The high-redshift Universe in X-rays

Andrea Comastri (INAF-OA-Bologna)

Piero Ranalli (Bologna University- INAF), Roberto Gilli (INAF), Cristian Vignali (Bologna University-INAF), Fabrizio Fiore (INAF), Marcella Brusa (MPE), Francesca Civano (SAO-CfA), Elisabeta Lusso (Bologna University-INAF), Ioannis Georgantopoulous (INAF), Kazushi Iwasawa (INAF & ICREA), Mara Salvato (IPP)

The high-z Universe: open issues

Future facilities (ALMA,LOFAR, JWST…) will investigate high-z galaxies and AGN in many bands. Questions for a future X-ray observatory:

How and when do early BHs form and grow?
What triggers nuclear activity?
How do accretion modes evolve? [radiative efficiency, L/L_{Edd}, SED(α_{ox})]

What formed first, BH or galaxy?
Some evidence for larger BH per fixed stellar mass at z~0.3-0.6 (Treu+06,Woo+08).
Also, suggestions for M_{BH}/M_{*}~0.1-0.3 in bright QSOs at z>4 (Walter+04, Maiolino+07)
How do they co-evolve ? (obscured growth, feedback, bright QSO sequence ?)
What is the high-z BH mass function?

SDSS selected MASSIVE (> 10^9 M_{SUN}) QSO at z > 6 ARE THE TIP OF THE ICEBERG … --> MUST BE A POPULATION …

Semi analytic models of BH growth

Merging of Dark Matter Halos with cosmic time (LCDM) + recipes for the baryon physics. Press-Schechter formalism or Millenium Simulations to get halo merger trees.
(Volonteri+06, Rhook&Haehnelt08, Menci+08, Marulli+08, Volonteri+10 review)

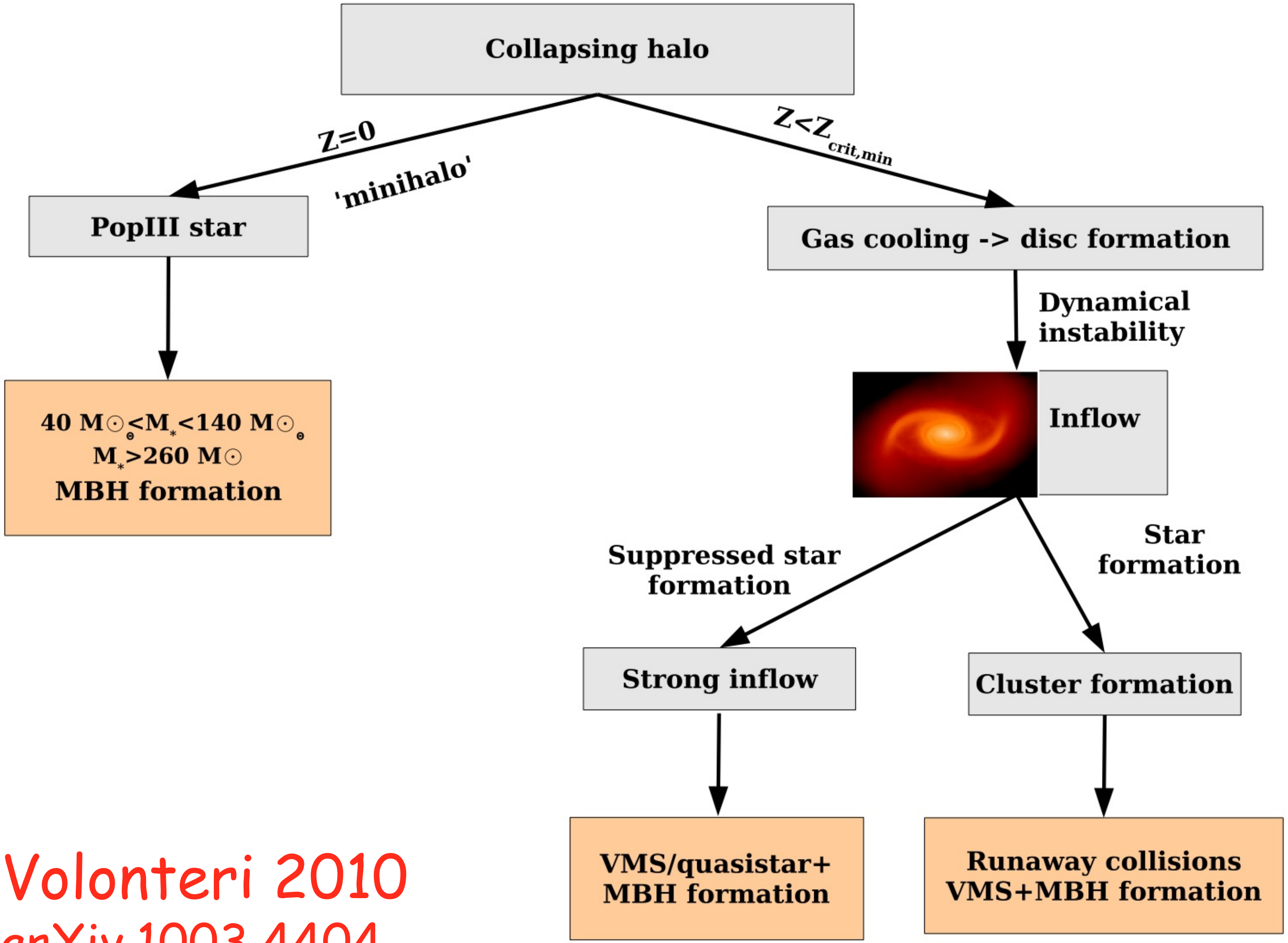
Common assumption: nuclear trigger at merging

Free parameters:

✧ BH seeds
  Direct Collapse : Heavy Seeds
  Runaway Merging : Intermediate Seeds
  Pop III : Light Seeds

✧ recipes for accretion ➔ Eddington ratio, AGN duty cycle, efficiency, …
✧ relation between initial BH mass and halo mass (e.g. bias)
✧ SED (e.g. obscuration) and Bolometric Luminosity
✧ room for accretion due to internal processes (i.e. not related to mergers)
✧ Probably many more …

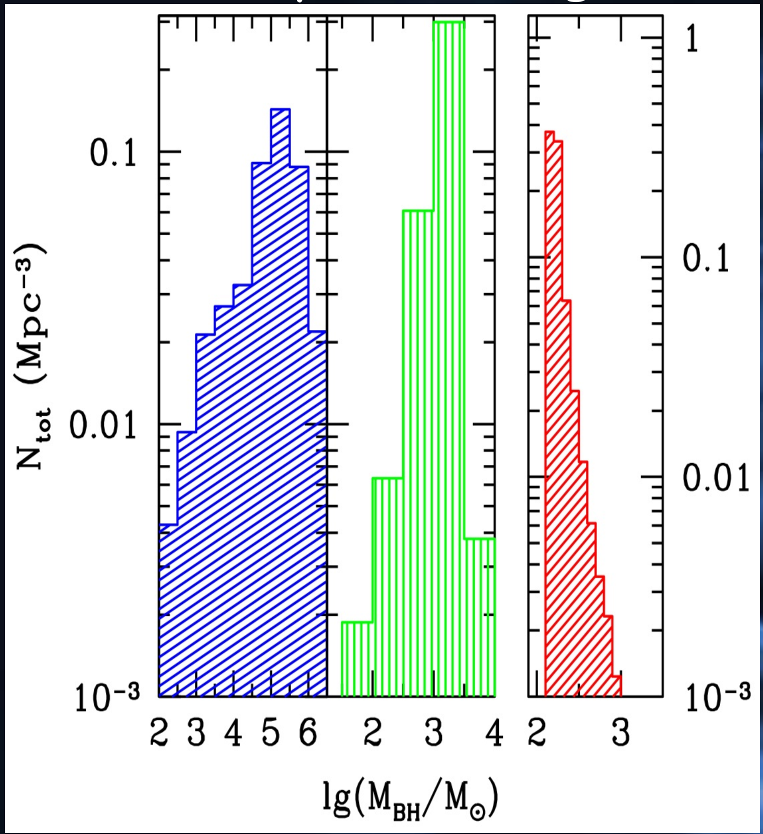
"Rees flow chart"



Volonteri 2010
arXiv.1003.4404

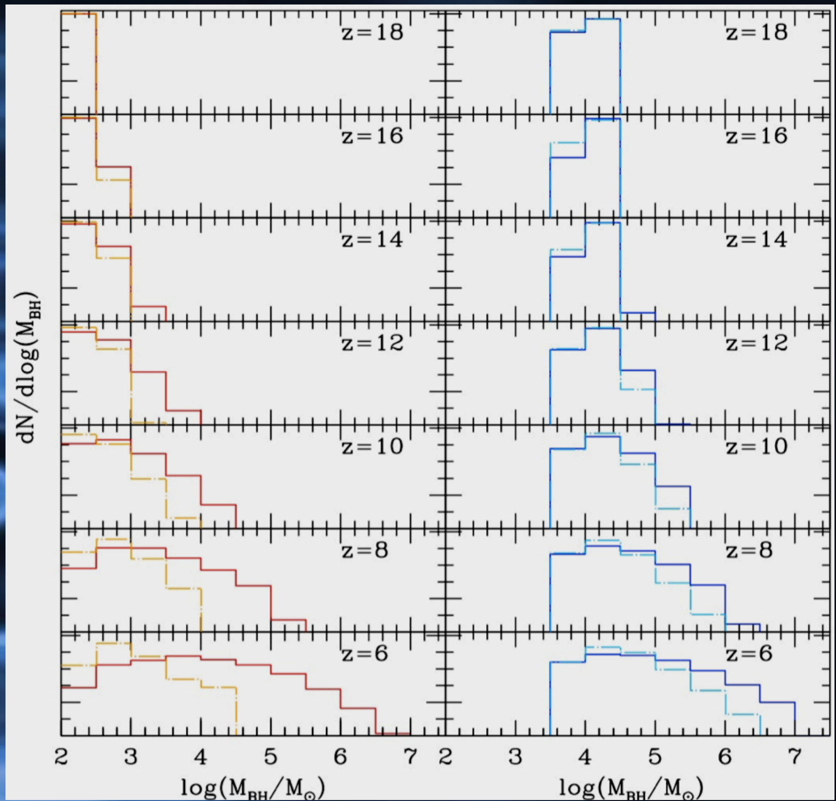
Seed Mass function

Heavy -------> light



Small Seeds -------> Large Seeds

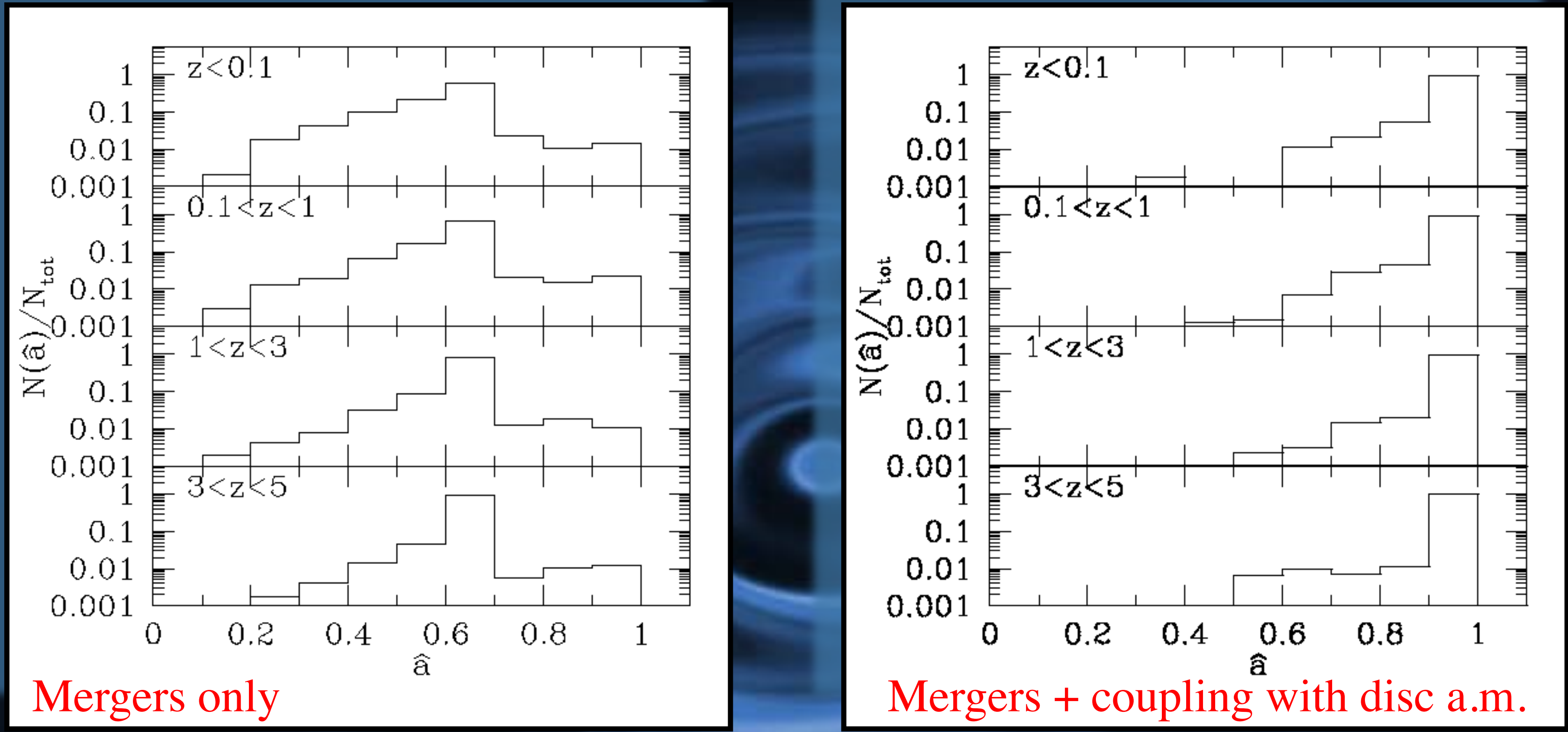
Solid=Eddington - Dotted=Edd. Ratio Distr.



$$M(t) = M(t_0) \exp\{ \varepsilon_L \; (1 - \varepsilon_M) / \varepsilon_M \; * \; (t - t_0) / t_E \}$$

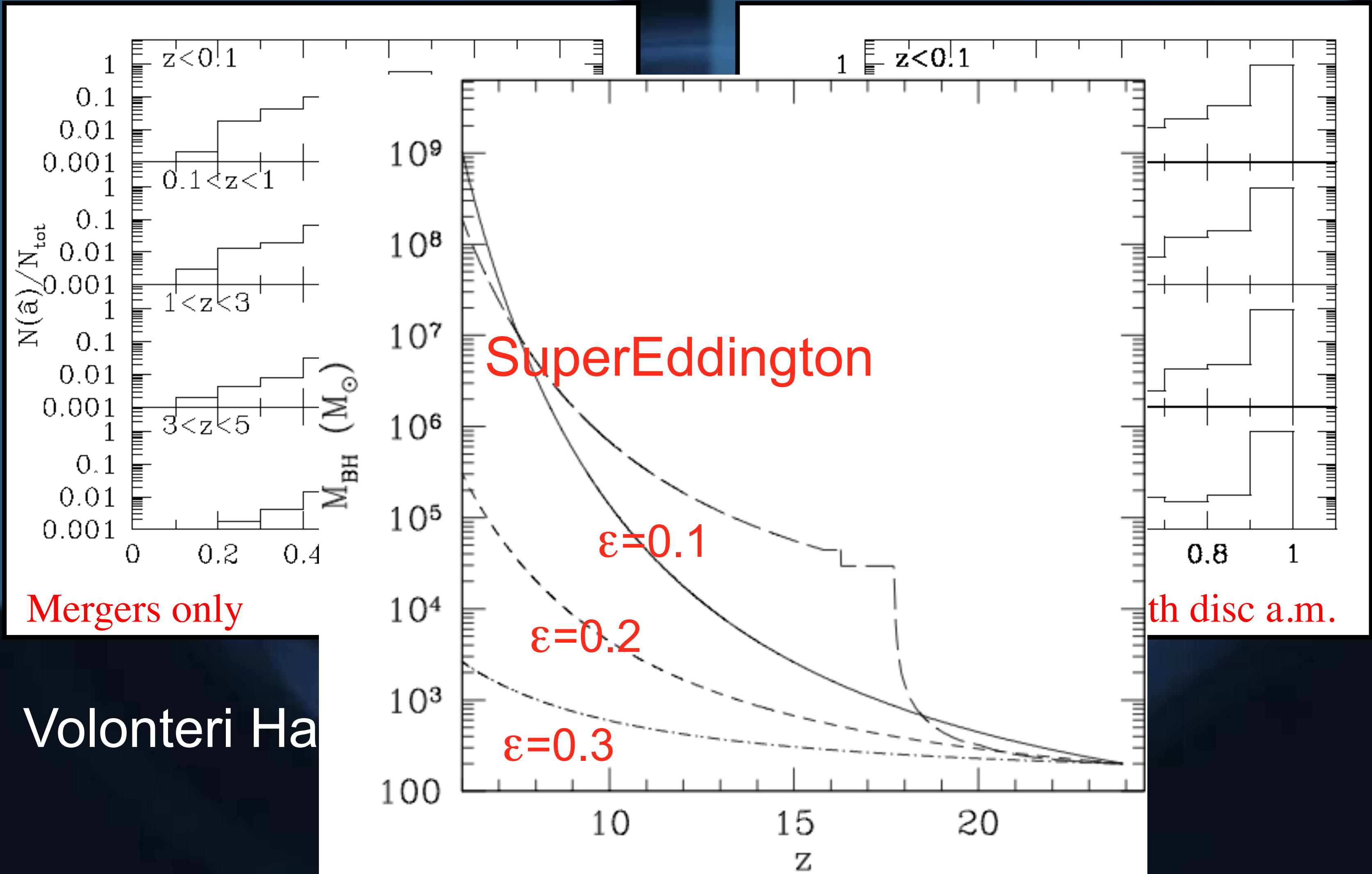
$t_E = 0.45$ Gyr $\varepsilon_L = L / L_E$ $\varepsilon_M = L / \dot{M} c^2$

Evolution of BH Spins



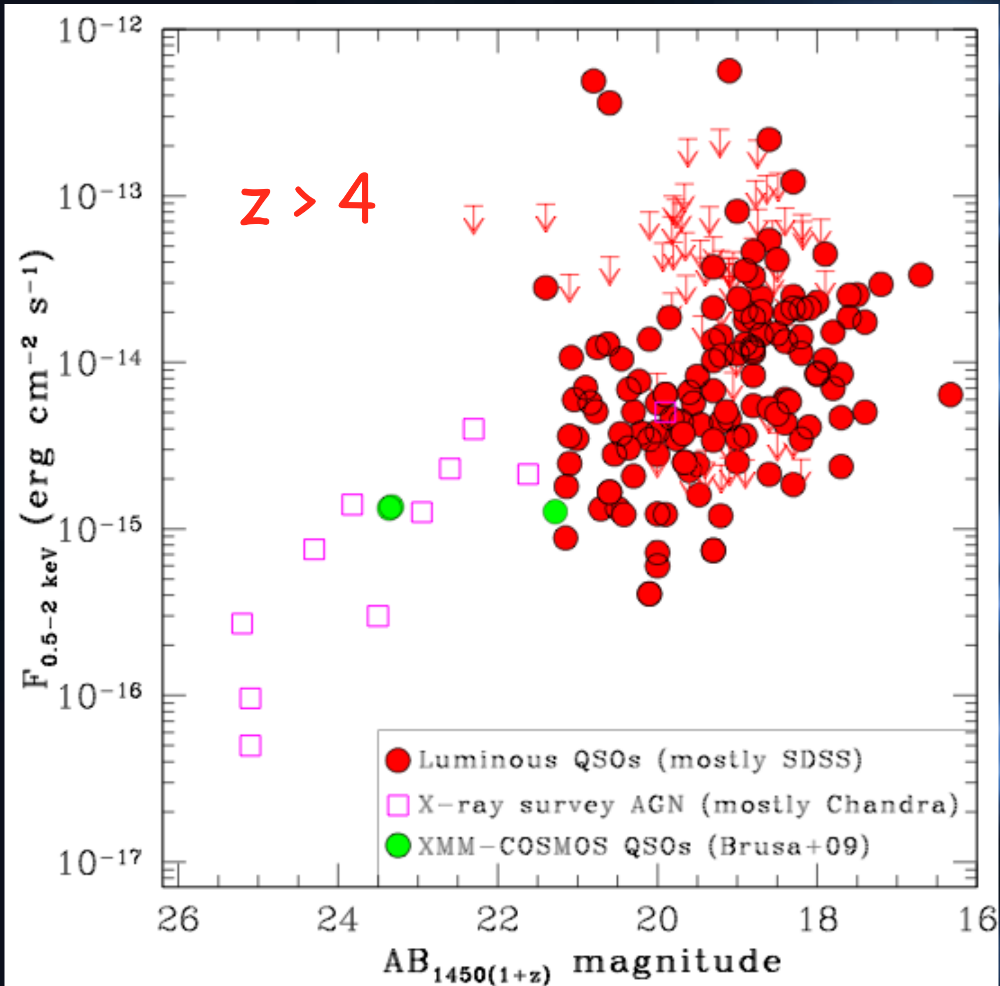
Volonteri Haardt Madau 2005

Evolution of BH Spins



Volonteri Ha

Optically selected vs X-ray selected

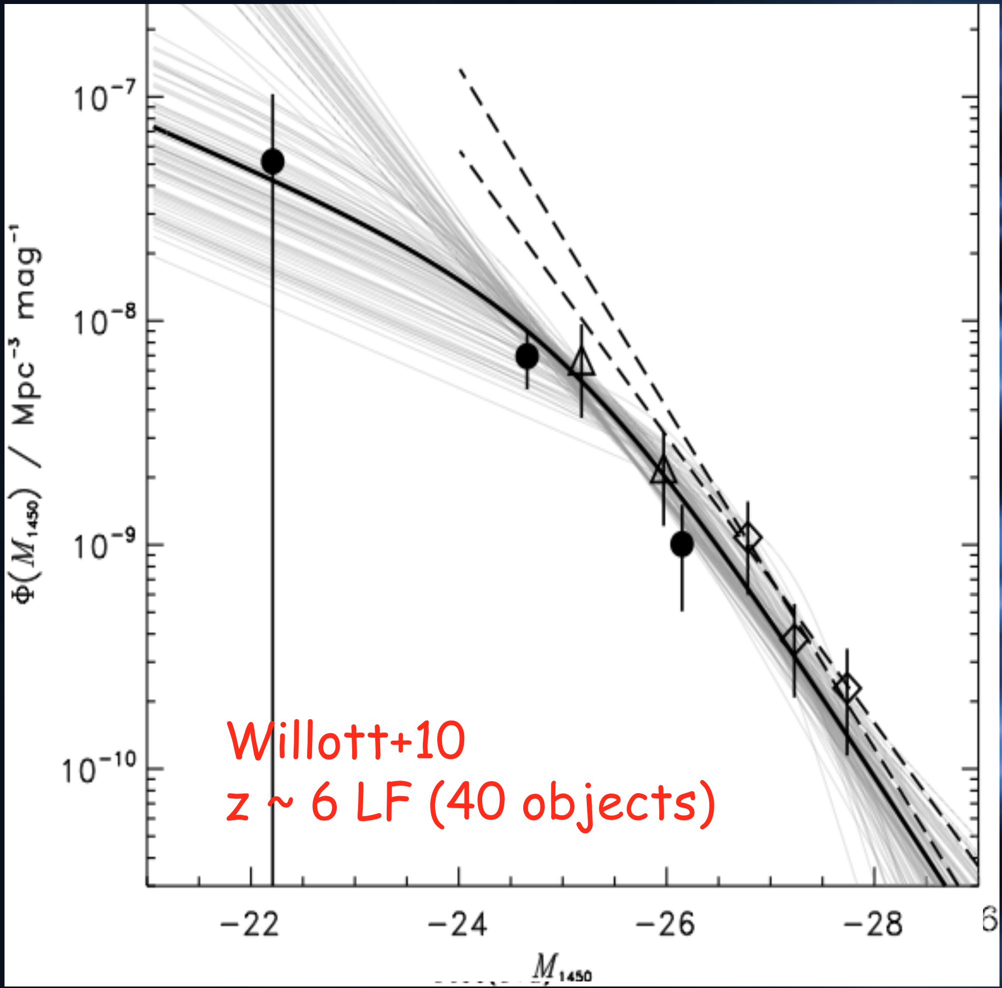


The number of high-z AGN detected so far

	SDSS	X-ray sel.$
z > 3	8000	~100
z > 4	1500	~ 15
z > 5	150	~ 3-4
z ~6	40	~ 0

$ see eg. compilations by Silverman+08, Hasinger08; Brusa+09; Civano+10;

Optically selected vs X-ray selected

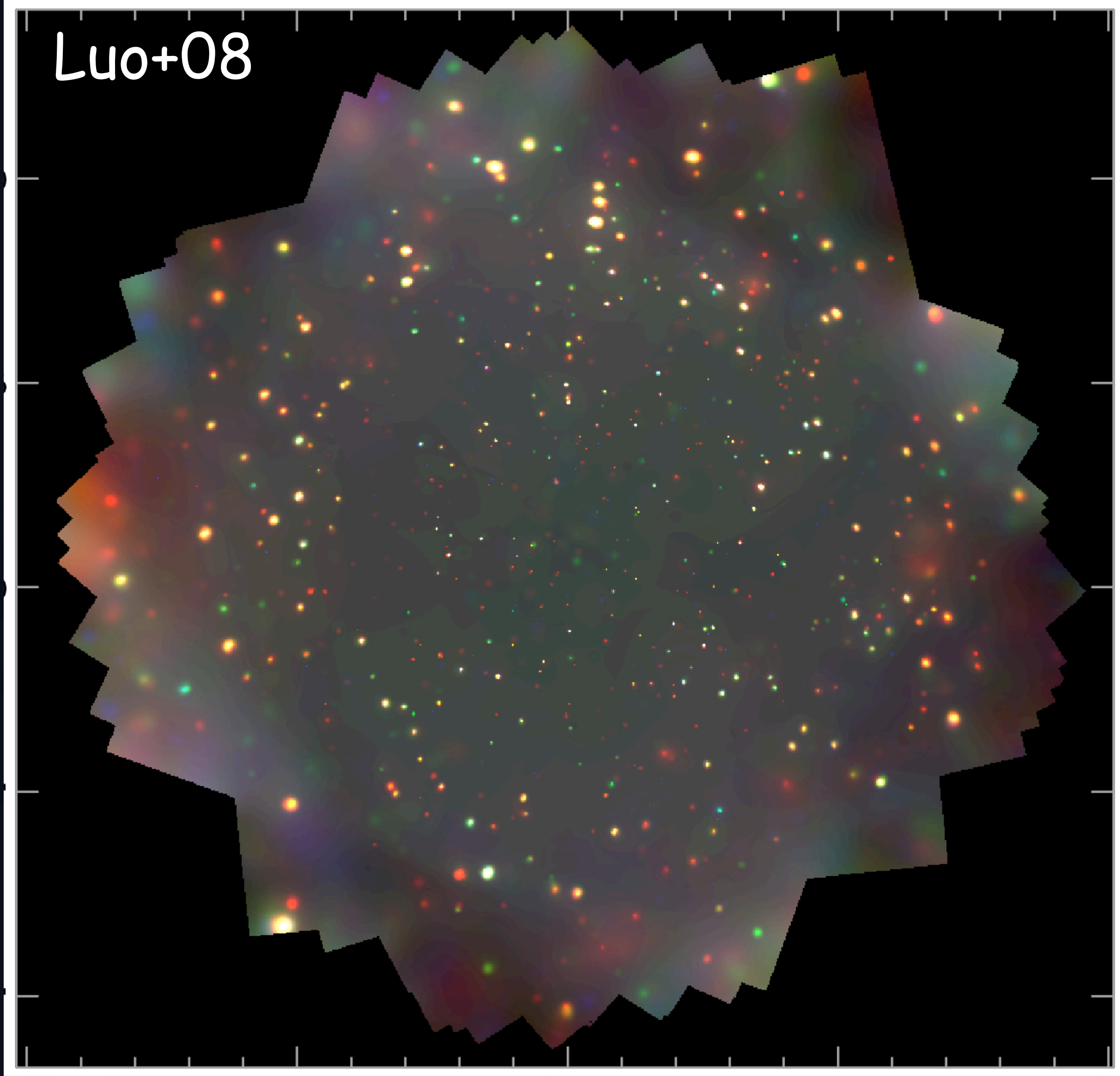


The number of high-z AGN detected so far

	SDSS	X-ray sel.$
z > 3	8000	~100
z > 4	1500	~ 15
z > 5	150	~ 3-4
z ~6	40	~ 0

$ see eg. compilations by Silverman+08, Hasinger08; Brusa+09; Civano+10;

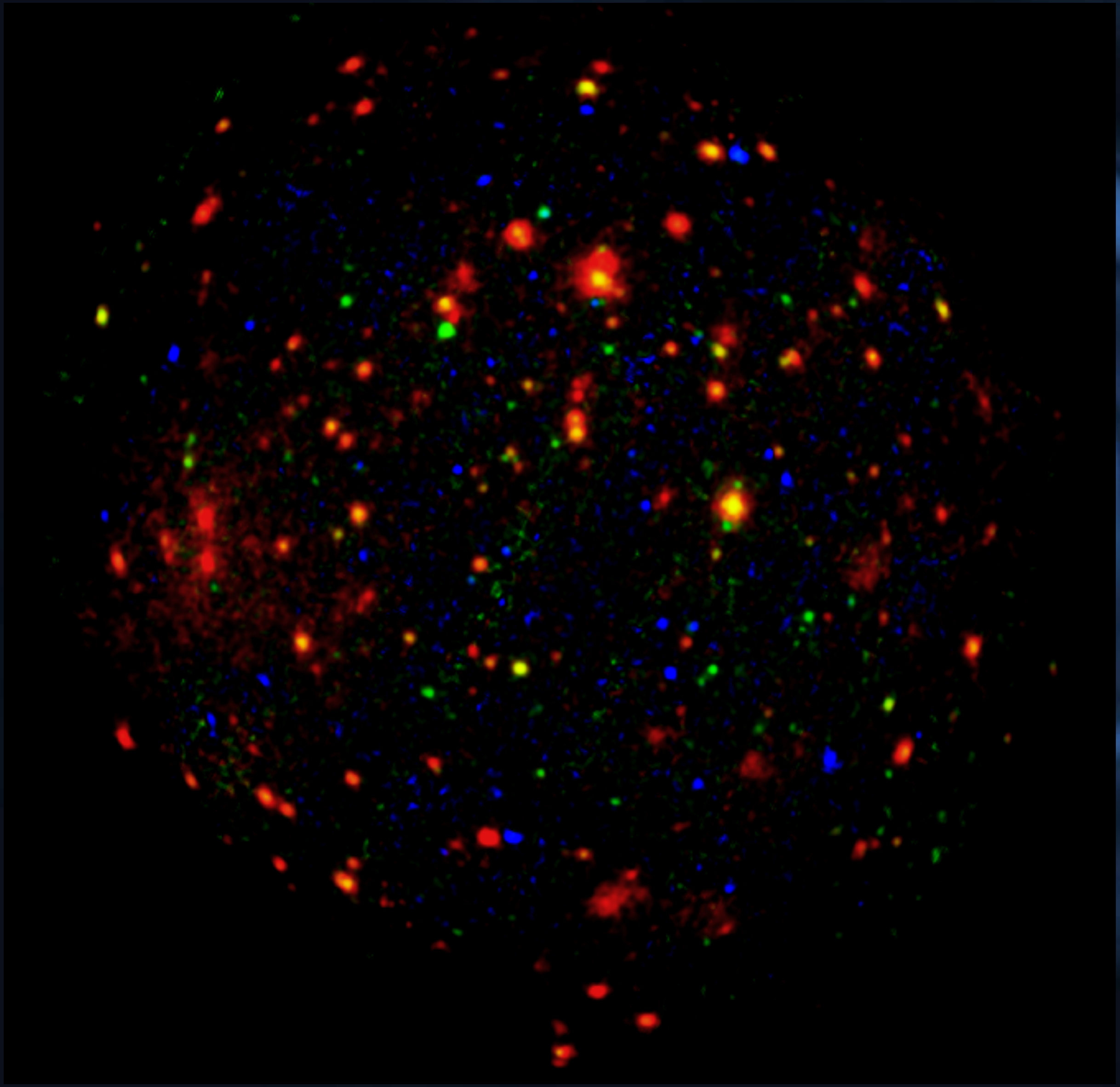
Deep X-ray surveys



Chandra 2 Ms

will be 4 Ms
in 2011

Deep X-ray surveys

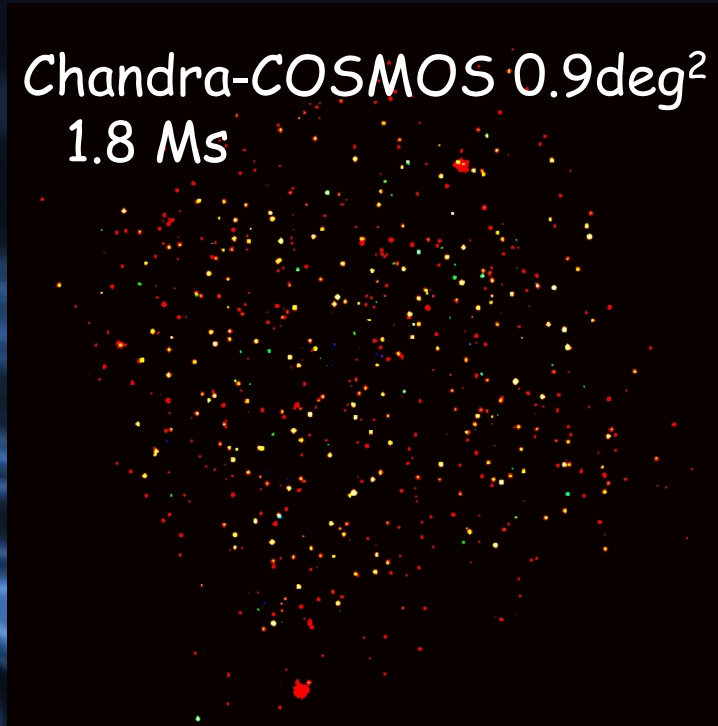


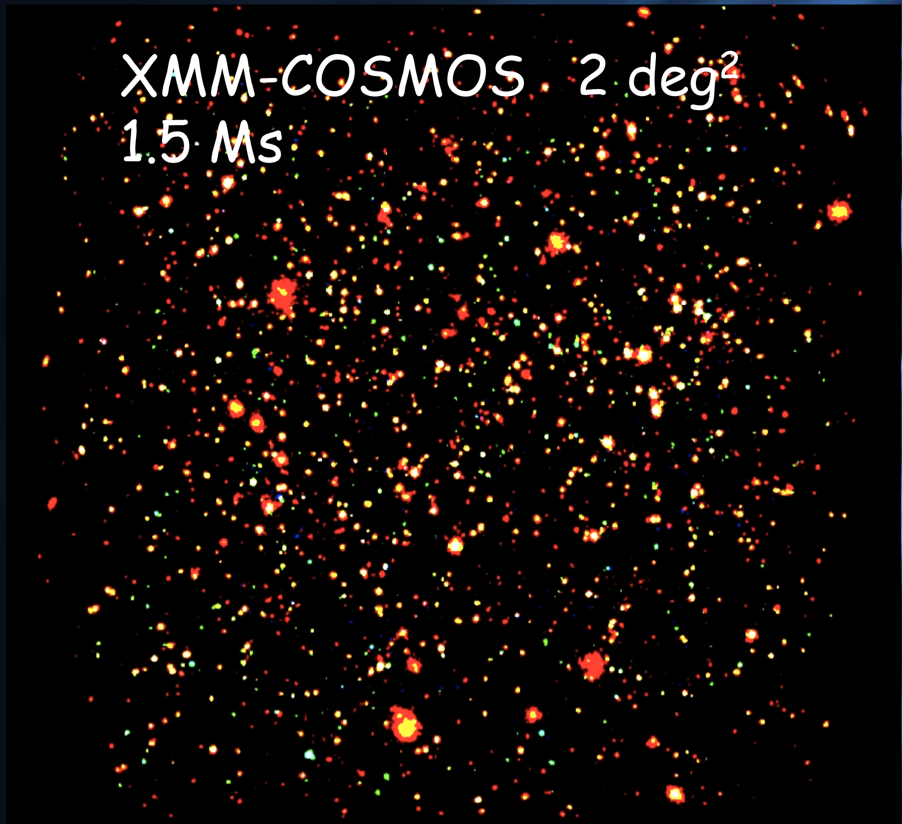
Chandra 2 Ms

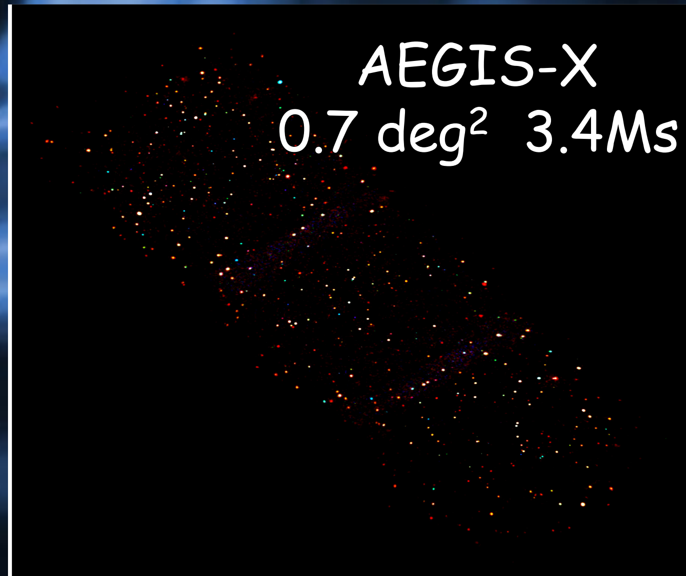
will be 4 Ms
in 2011

XMM ~ 1.5 Ms
has reached
~ 2.7-3 Ms

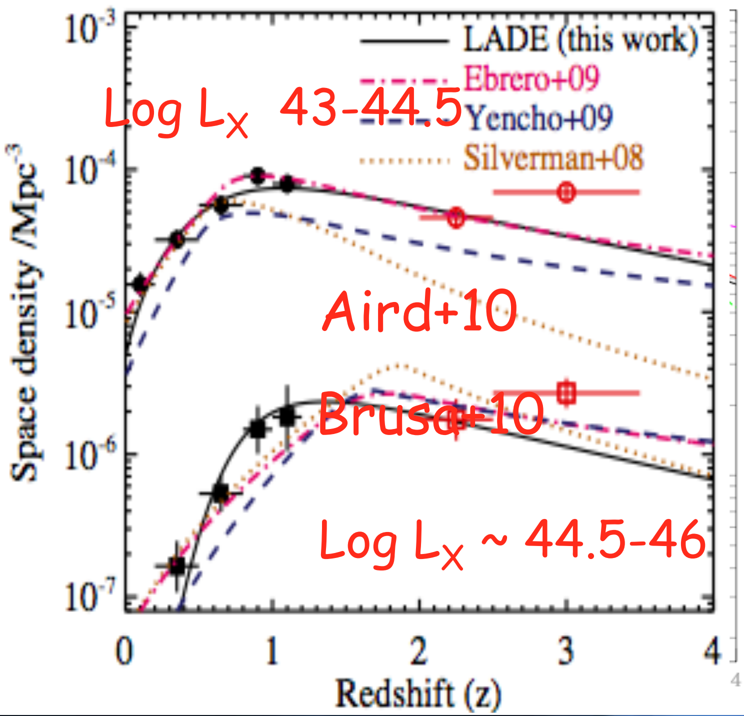
Large area X-ray surveys

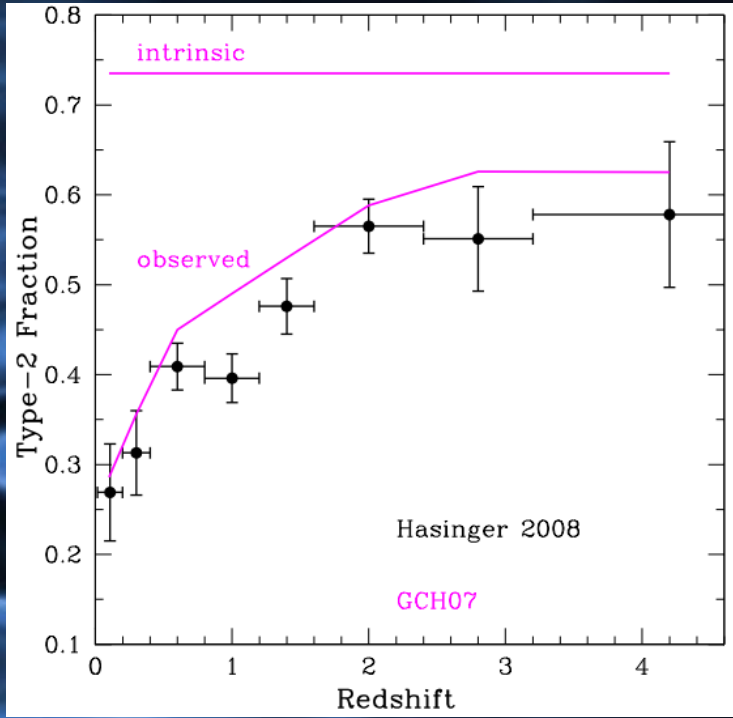






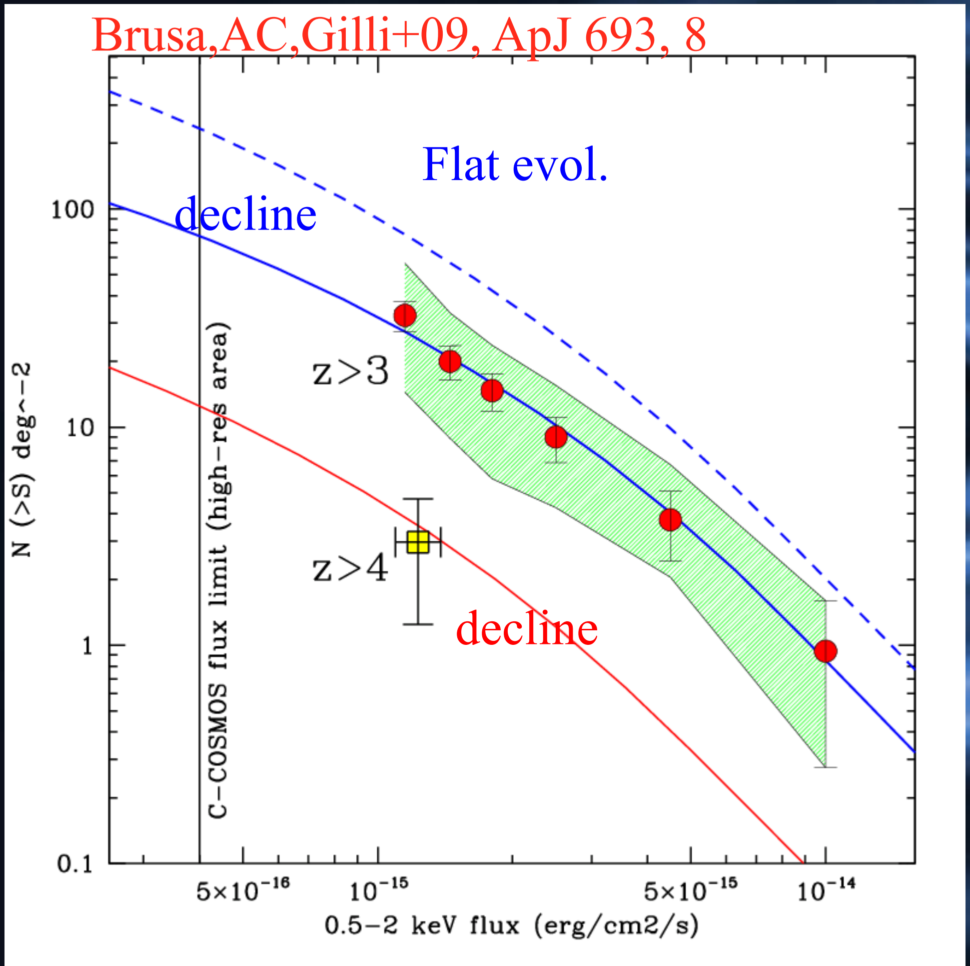
X-ray luminosity function



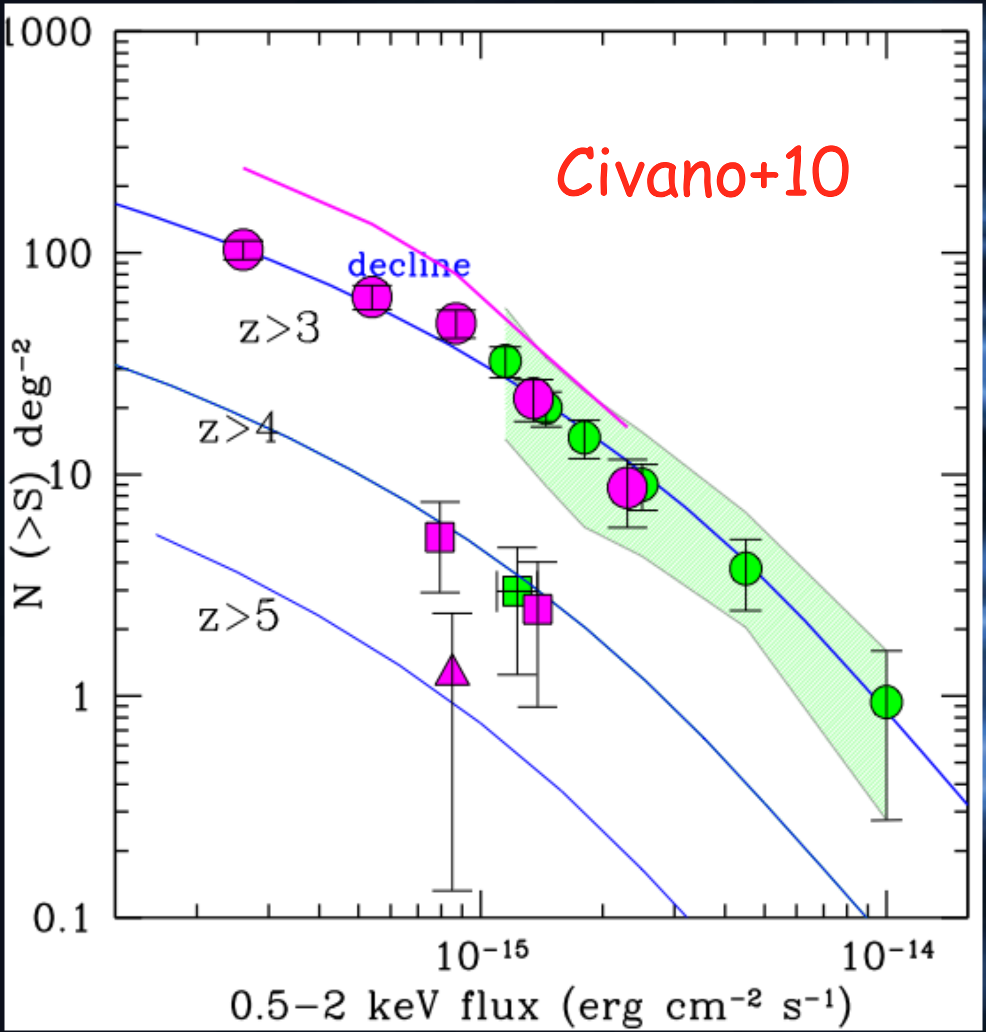


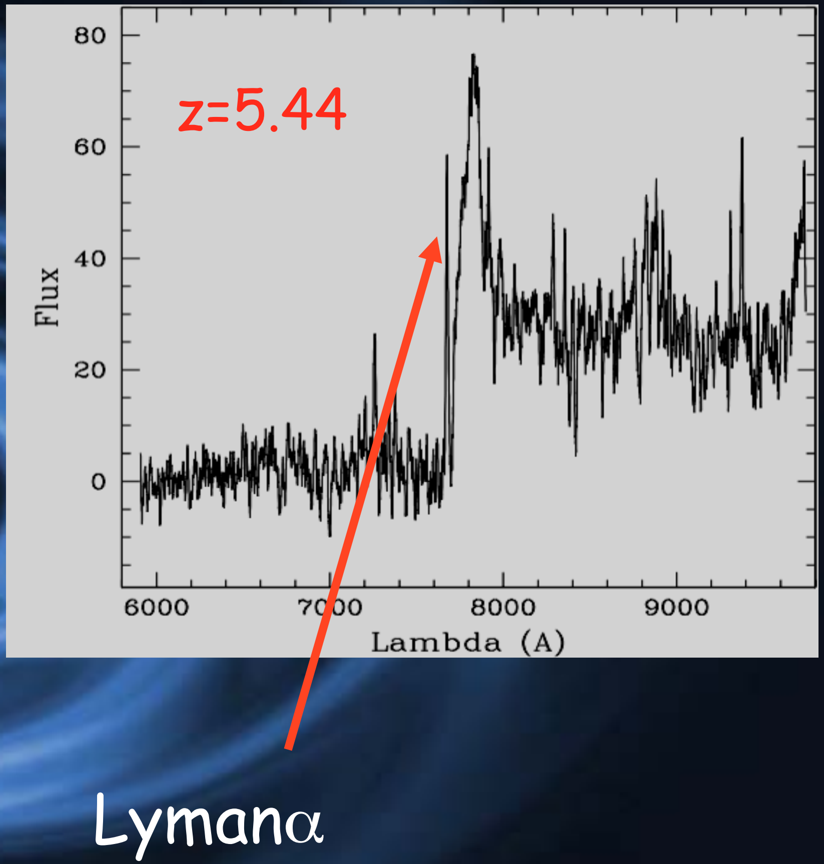
expected/predicted in feedback models (i.e. Menci+08)
Seen in (some) data [e.g. La Franca+05, Treister+06, Hasinger08], not seen in others (Ueda+03, Dwelly&Page 2006), not needed in XRB models (Gilli+07)

Chandra COSMOS

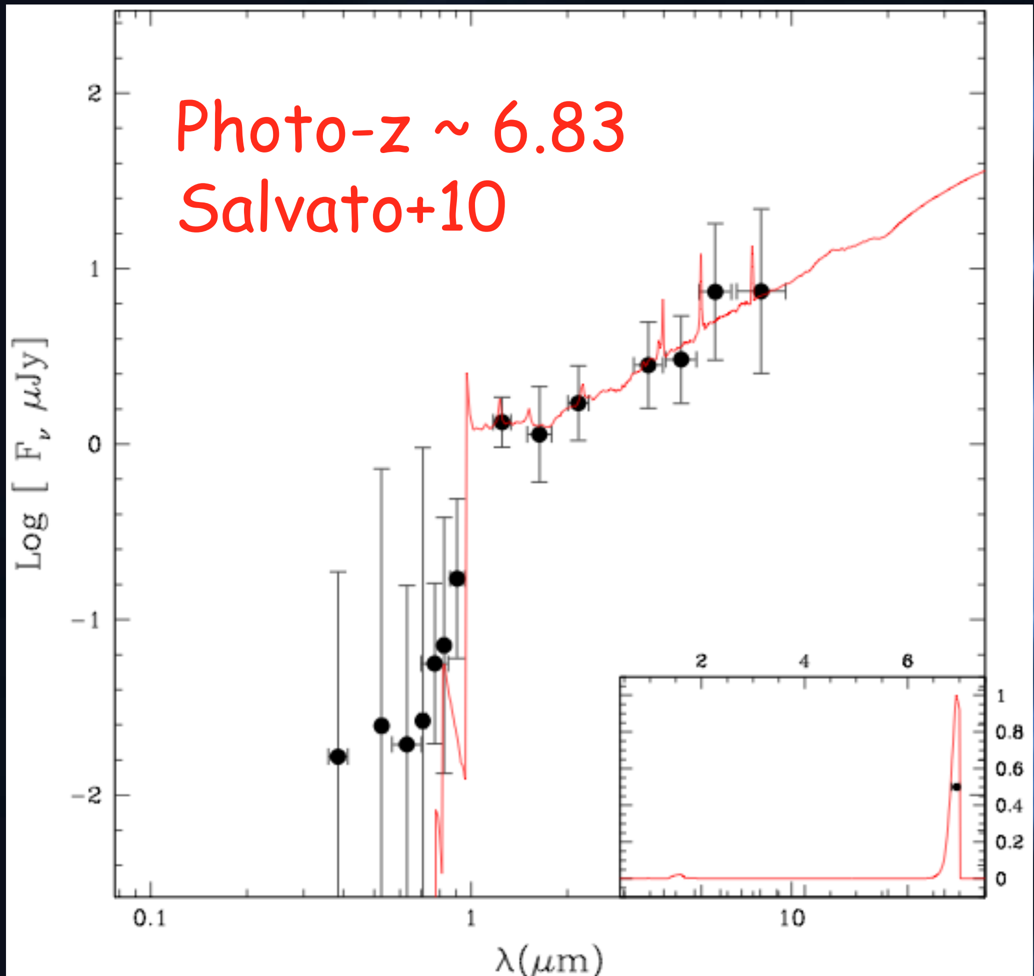


Chandra COSMOS





The highest z QSO ?



Chandra COSMOS

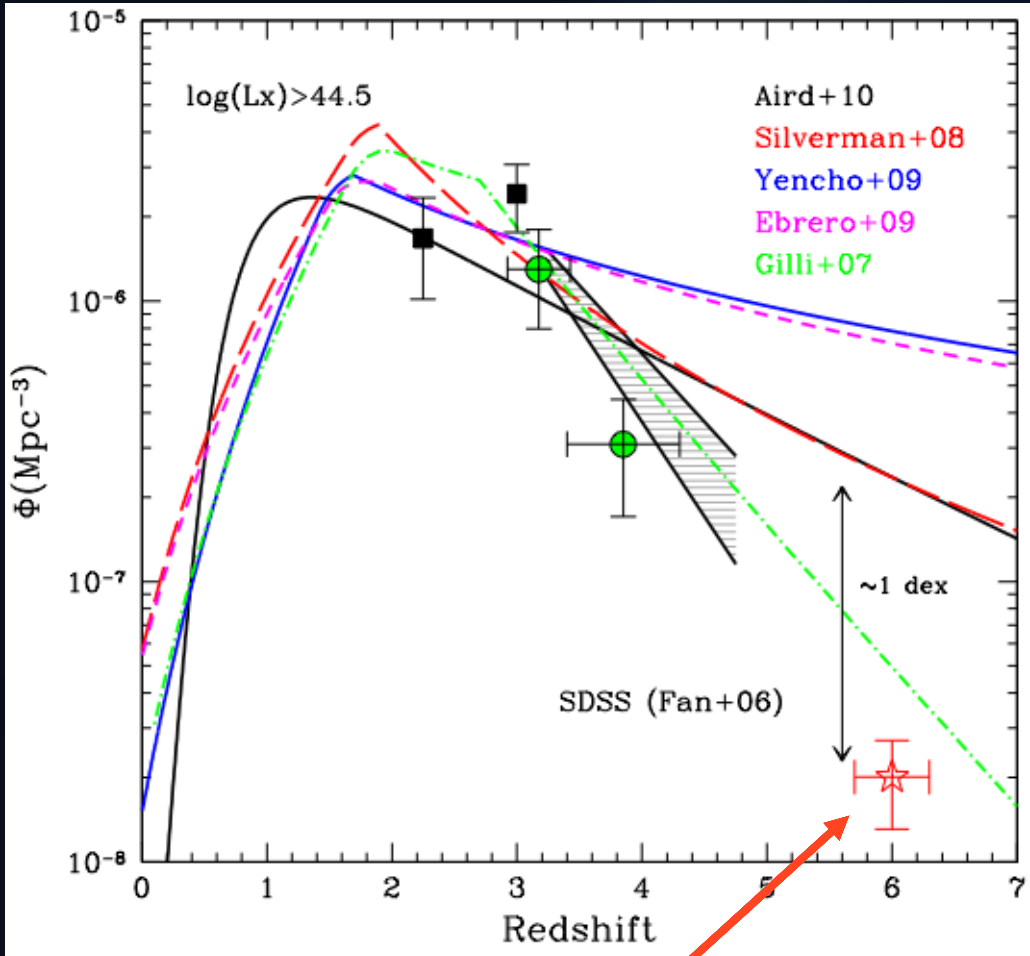
$F_X \sim 2.\ 10^{-16}$ cgs

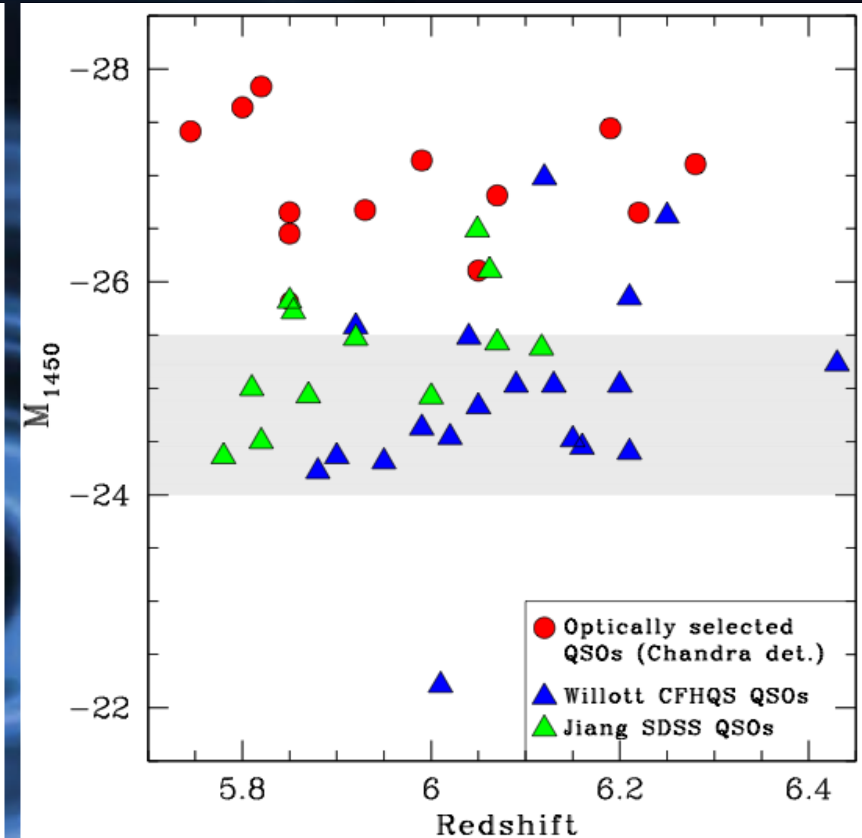
$L_{2\text{-}10\ keV} \sim 10^{44}$ cgs

z ~ 25.4
J ~ 23.6

Need of deep photometry

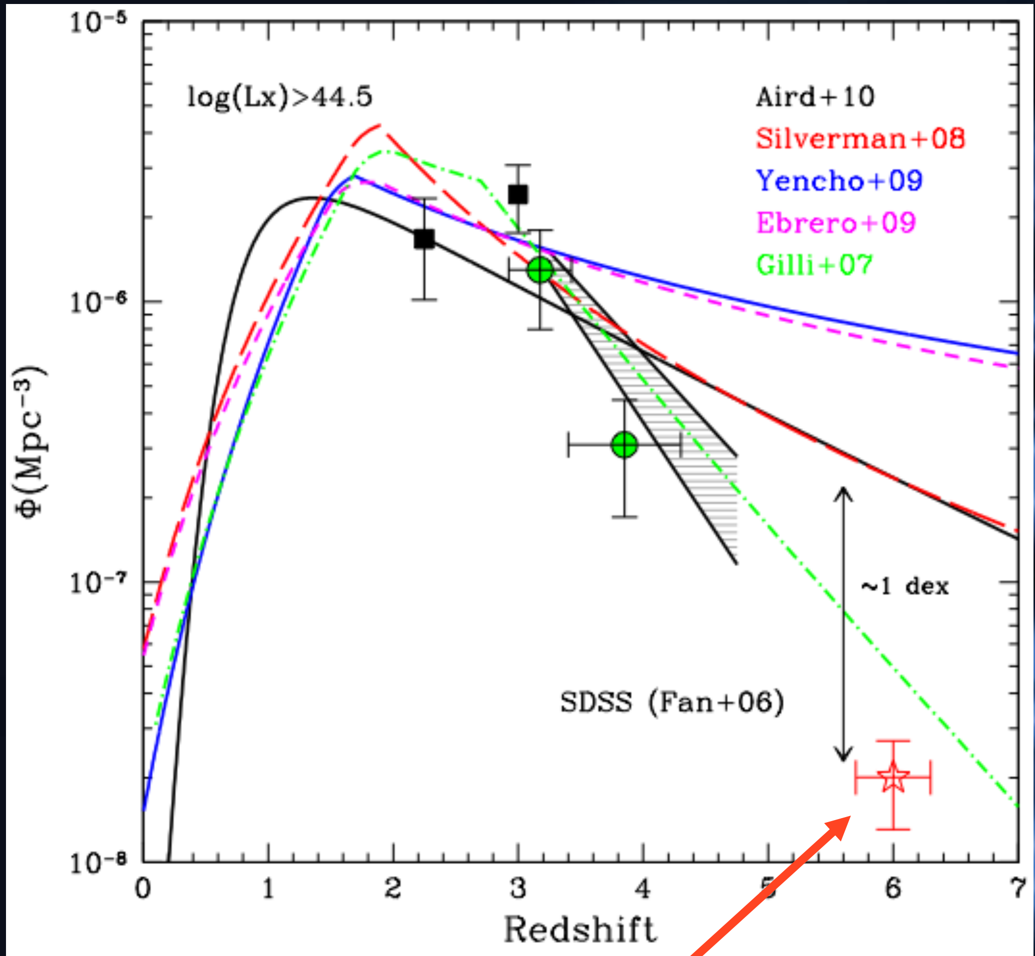
Searching for z ~ 6 QSO

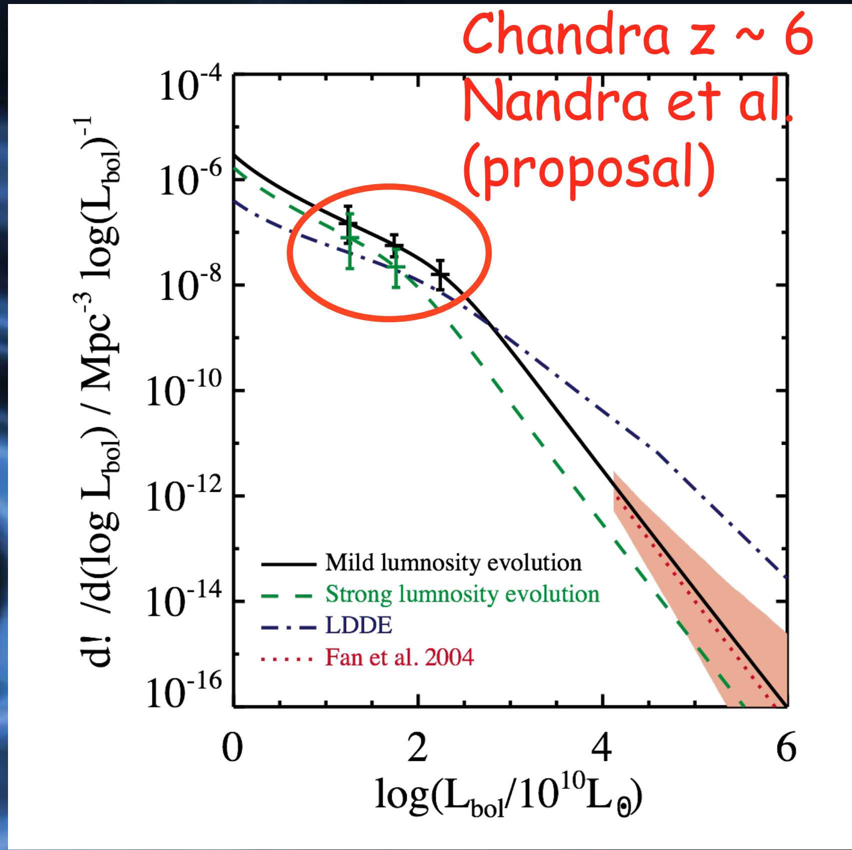




Estimated space density of Type 1 AGN from optical LF and narrow α_{OX} distribution centered at 1.6. (No obscured AGN)

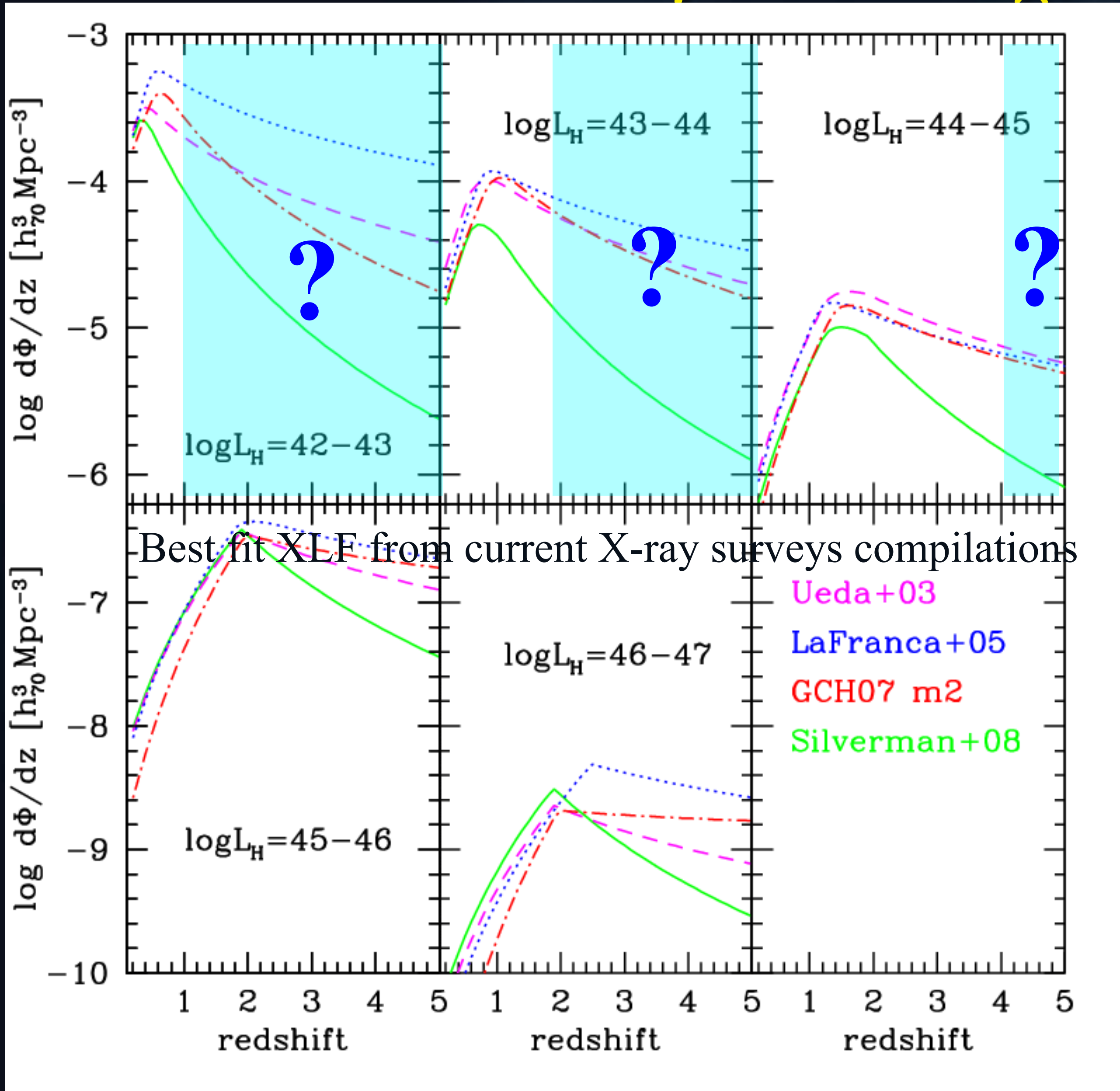
Searching for z ~ 6 QSO





Estimated space density of Type 1 AGN from optical LF and narrow α_{OX} distribution centered at 1.6. (No obscured AGN)

What's the density of low L_X, high-z AGN?



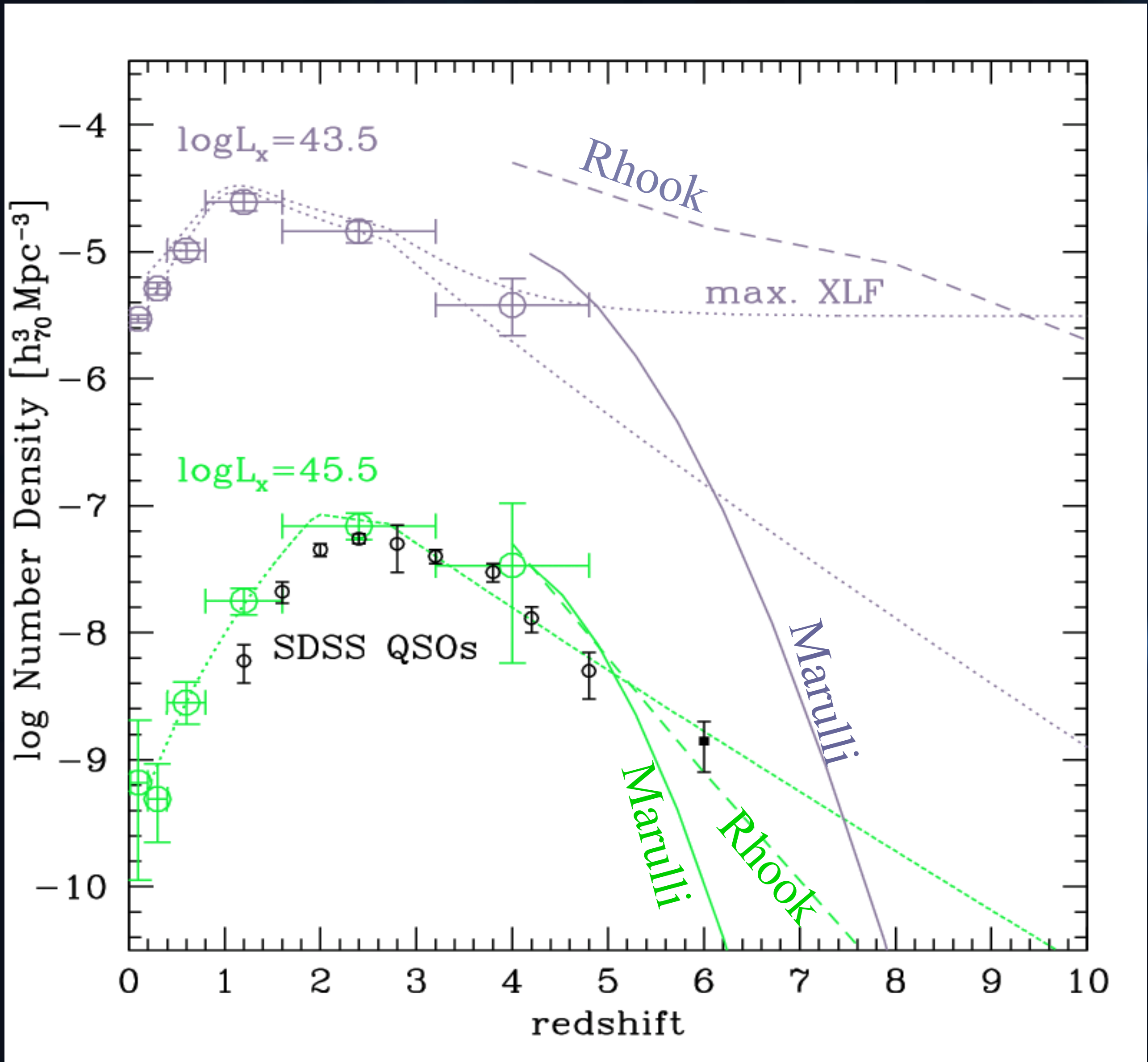
Evolution of the bulk of the AGN population still to be determined at moderate to high-z.

Flatter evolution or decline as for high luminosity?

Sensitivity needed for high-z AGN census

<u>What do we expect?</u>

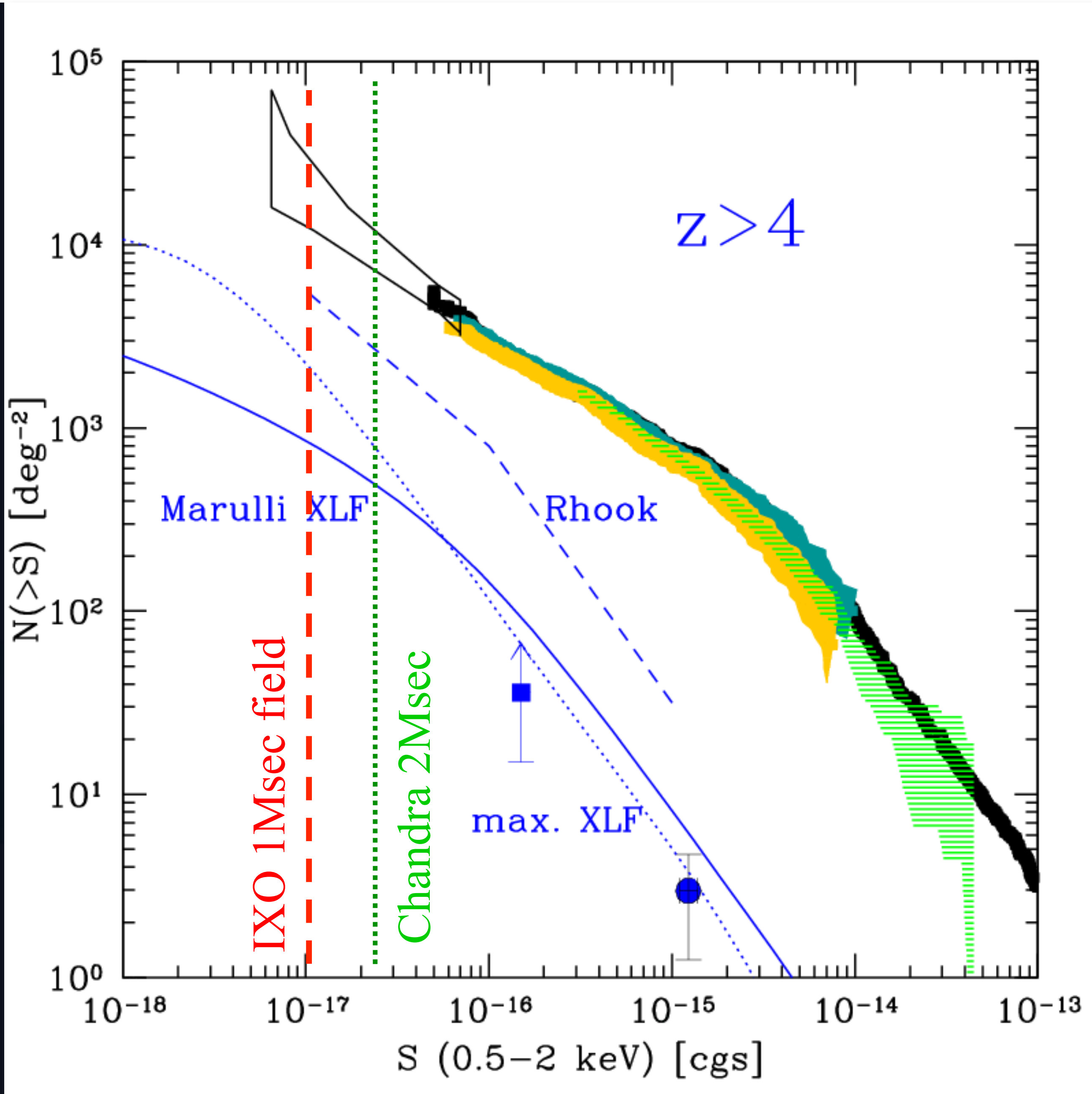
High-z AGN space density predictions



Very, Very uncertain …

max. XLF:

XLF that predicts the maximum number of high-z AGN while being in agreement with current "low-z" XLF.

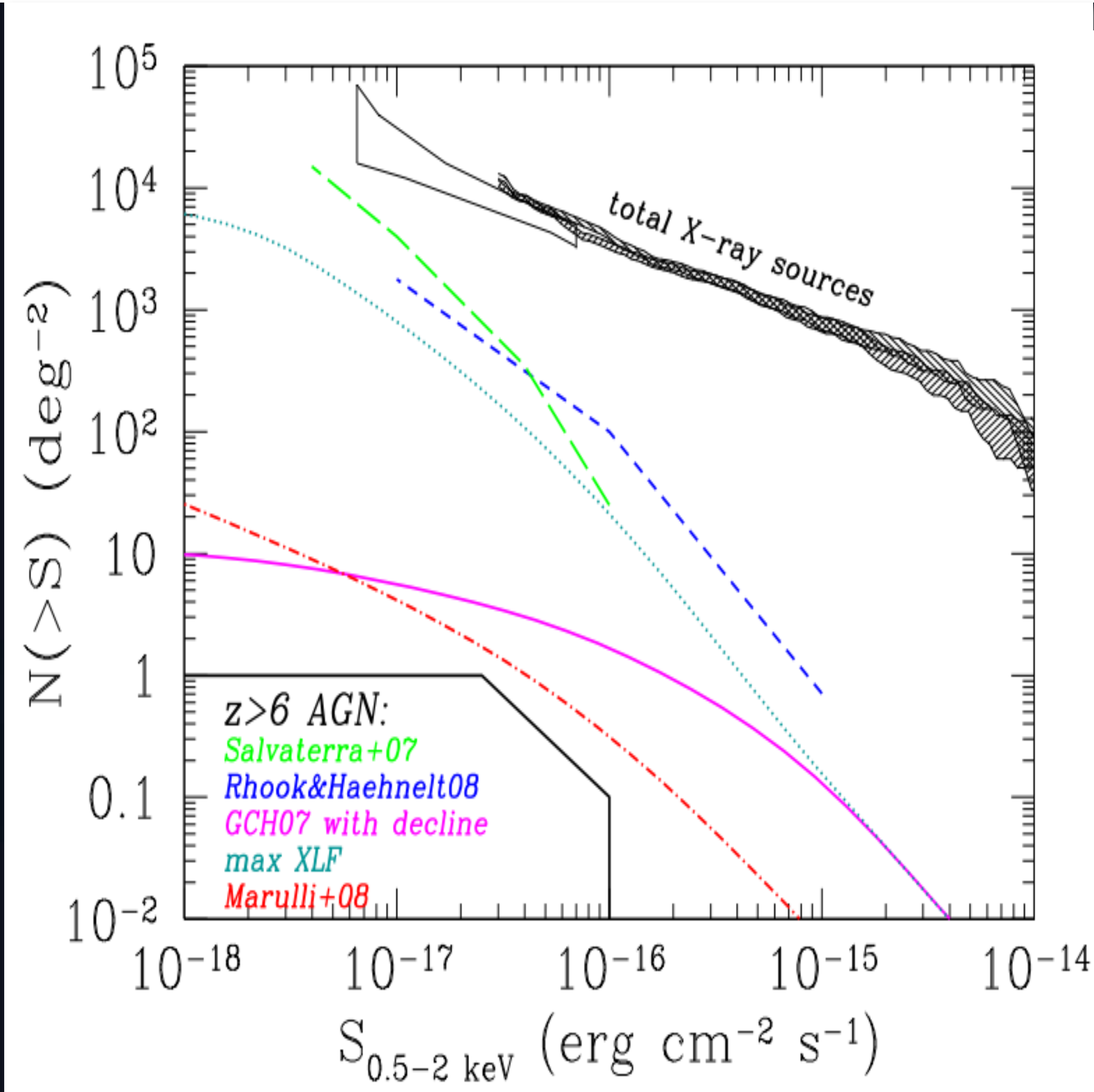


Confusion

at N(>S) ~ 2×10^4 deg^{-2},
i.e. S ~ 10^{-17} erg/cm^2/s

in ~1 Msec (depending on the bkg level)

XLF @ z > 6
would constrain the physics of early BH formation, seeds mass function, accretion mechanisms etc.



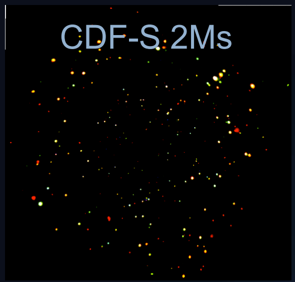
Confusion

at N(>S) ~ 2×10^{4} deg^{-2},
i.e. S ~ 10^{-17} erg/cm^{2}/s

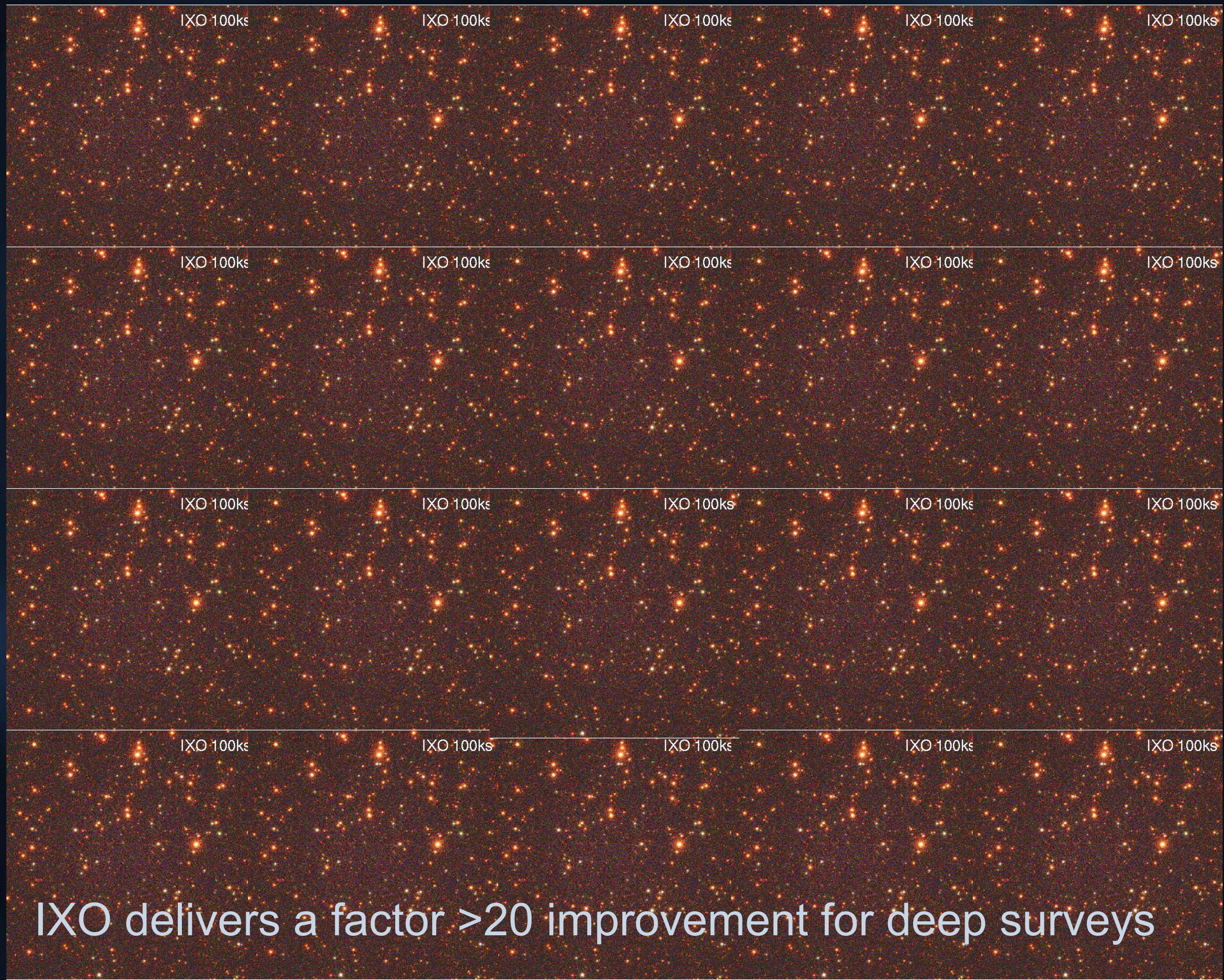
in ~1 Msec (depending on the bkg level)

XLF @ z > 6
would constrain the physics of early BH formation, seeds mass function, accretion mechanisms etc.

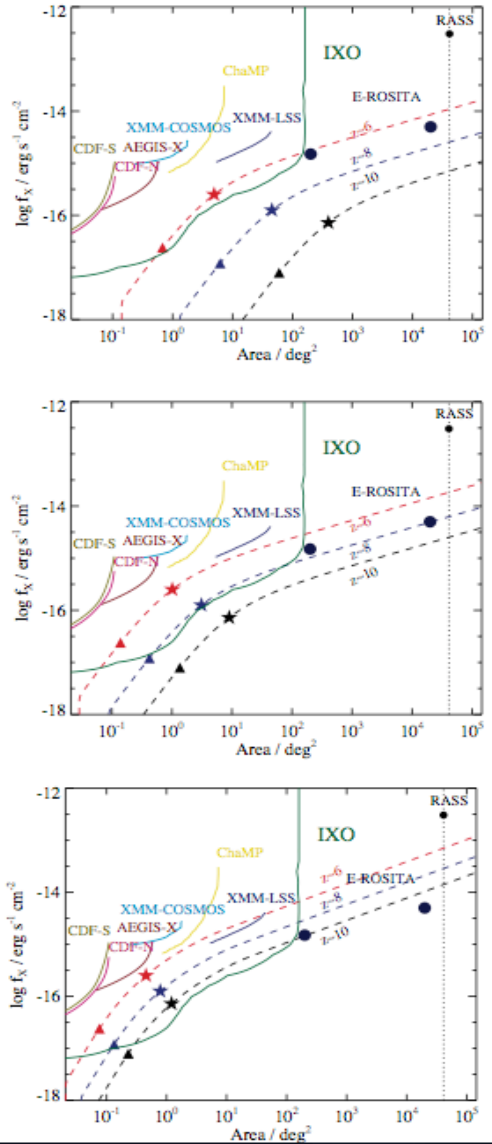
WHAT CAN IXO DO?



Credits: Nandra



WHAT CAN IXO DO?



PESSIMISTIC

Strong density evolution matching bright-end decline found by Brusa et al. 2009

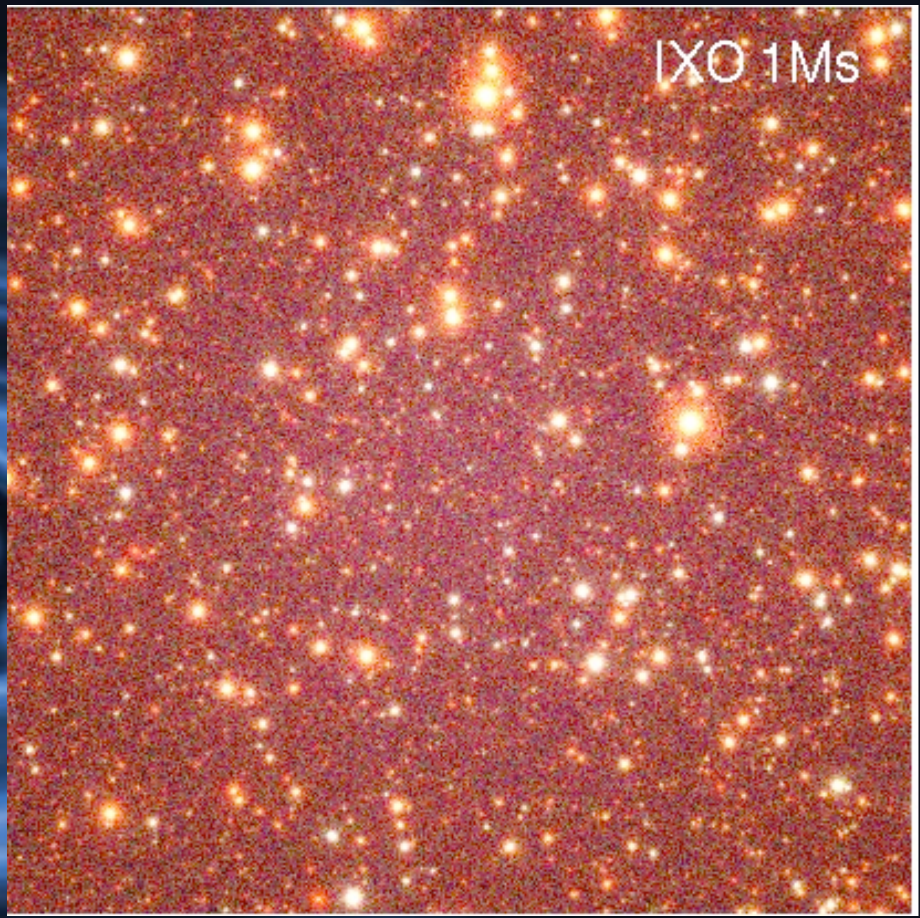
PRINCIPAL

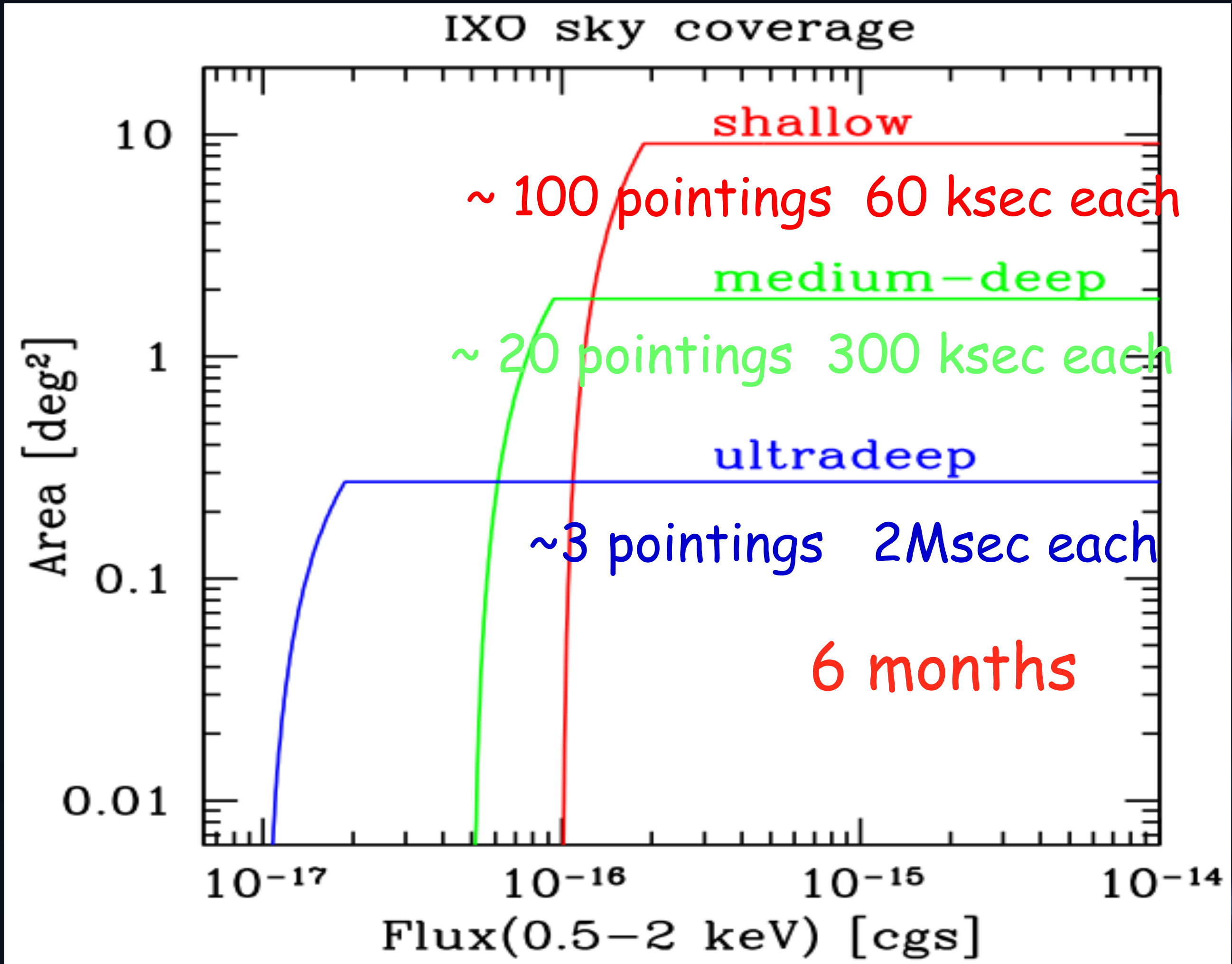
LADE model (Aird et al. 2009)

Aird+10

OPTIMISTIC

LDDE (Ebrero et al. 2009)





high-z AGN yields:
$N_{tot} \approx S^{1-\alpha}$

if $\alpha > 1$
deep in a single field

if $\alpha < 1$
wider areas

	Decline	maXLF	SAM
z > 4	355	1350	1375
z > 6	15	300	4

FOV ~ 18'x18'
Vignetting as in Willingale document

High-z AGN

A pure X-ray selection approach may not be "rewarding"

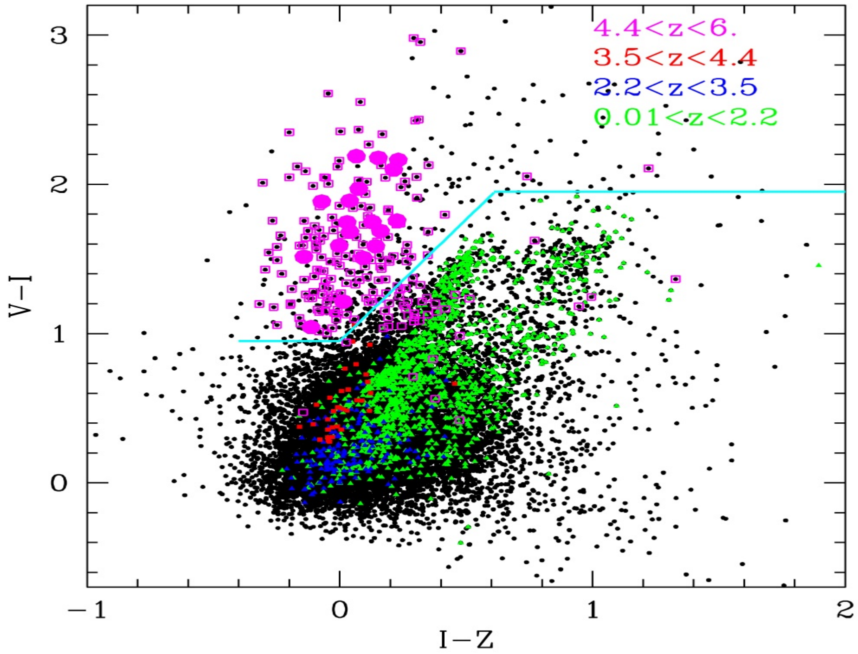
\+ obscuration biases free

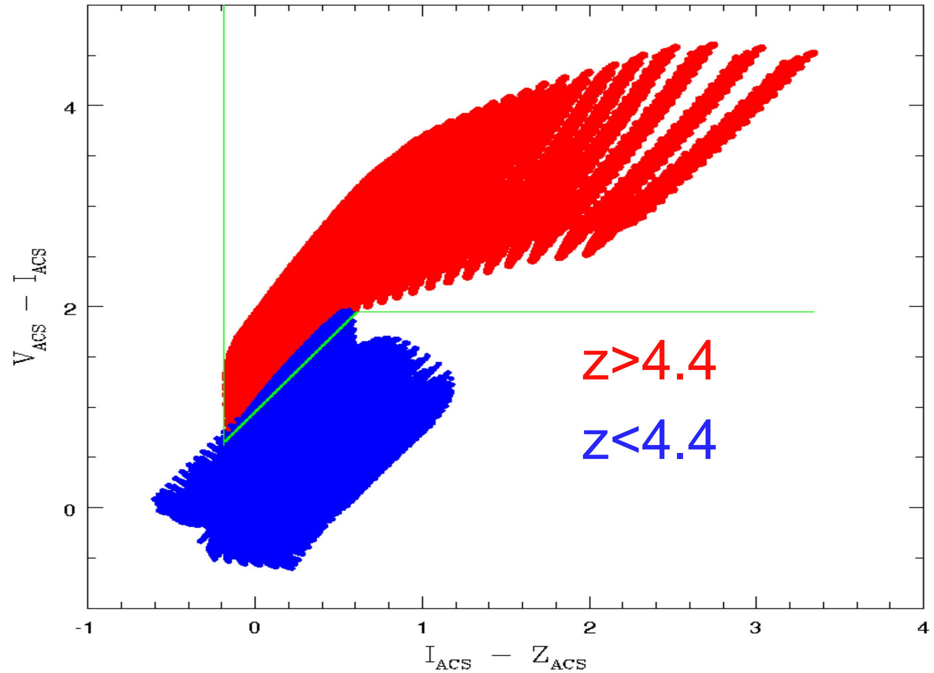
\- space densities are HIGHLY uncertain

A different approach: ***search for X-ray emission at the position of known high-z galaxies selected on the basis of multiwavelength data:***

- ***reach fainter X-ray fluxes***
- ***optimize the X-ray band***

High-z AGN in the CDFS 2Msec field



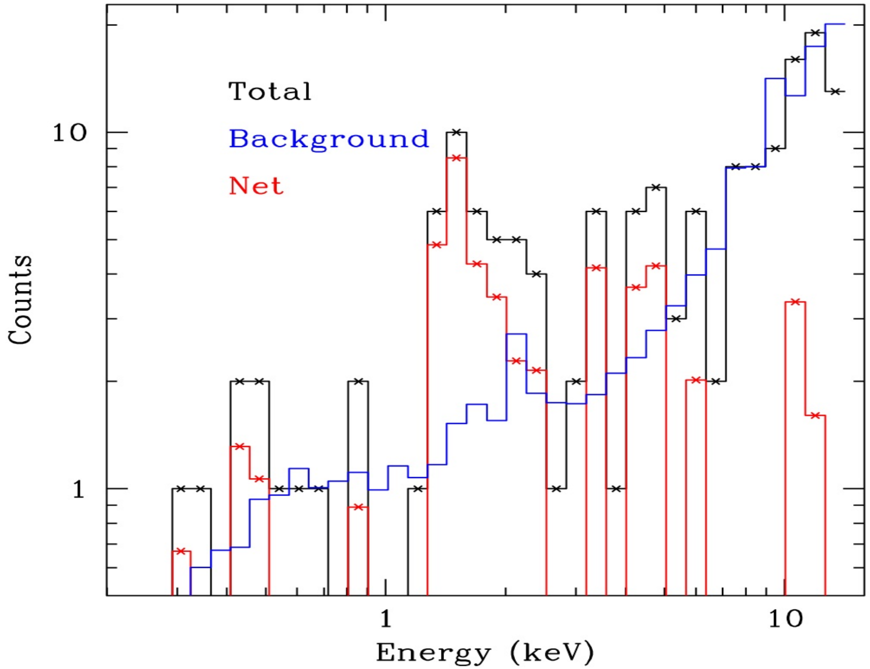


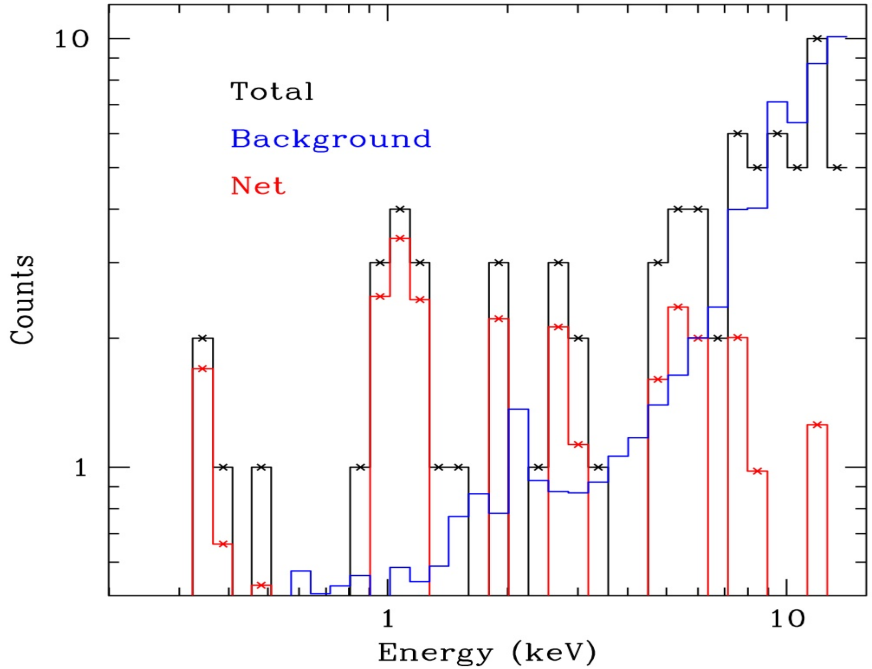
1. Use GOODS-MUSIC galaxy catalog: photo-z and B, V dropouts to build up a high-z galaxy candidate list.
2. Search for the X-ray band that maximizes the S/N of the detected counts. First step toward multi-dimensional source detection (background model)

32 z>3 AGN; 4 z>4.5 AGN, 14 (43%) *NOT* in Luo et al. catalog

Fiore et al. 2010 (in preparation)

High-z AGN in the CDFS 2Msec field



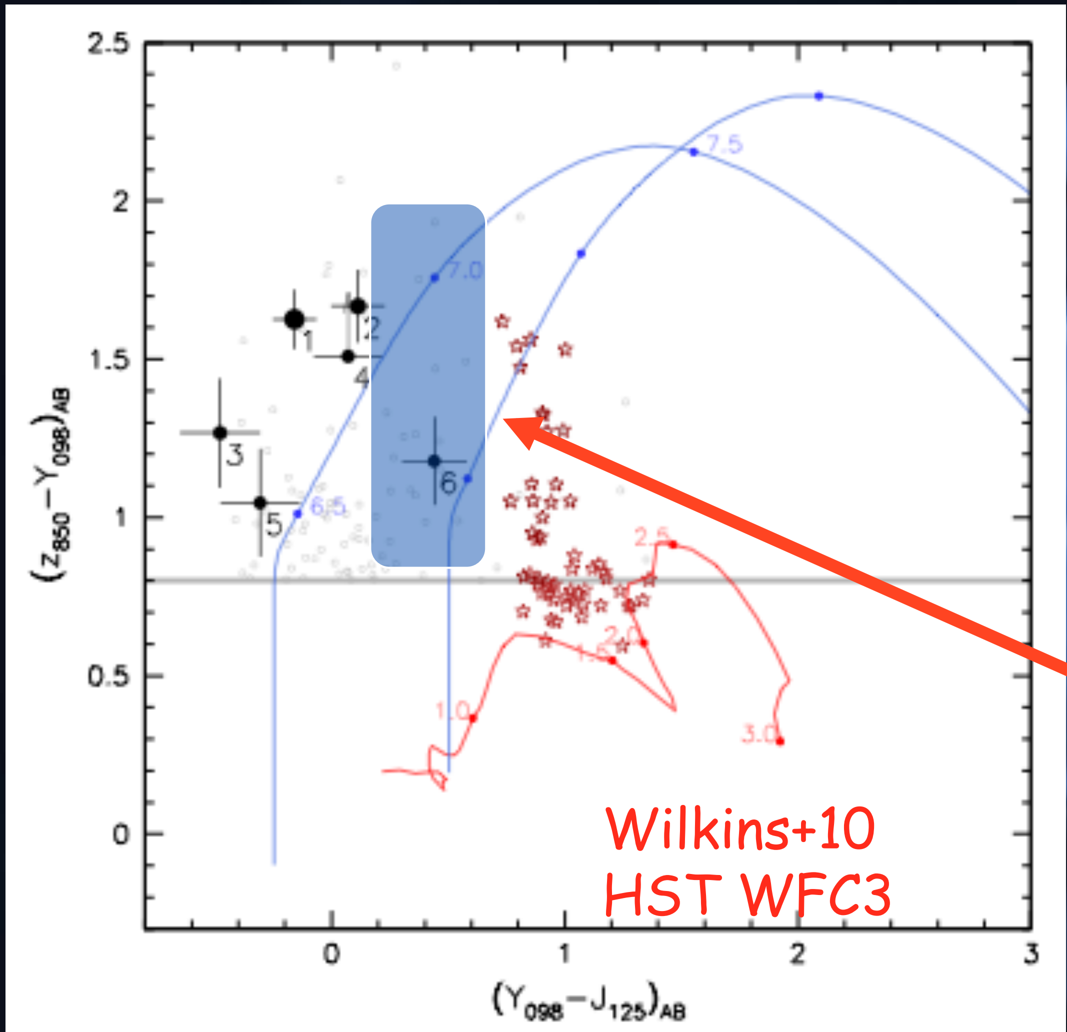


1. Use GOODS-MUSIC galaxy catalog: photo-z and B, V dropouts to build up a high-z galaxy candidate list.
2. Search for the X-ray band that maximizes the S/N of the detected counts. First step toward multi-dimensional source detection (background model)

32 z>3 AGN; 4 z>4.5 AGN, 14 (43%) *NOT* in Luo et al. catalog

Fiore et al. 2010 (in preparation)

High-z Drop Outs



Standard selection technique

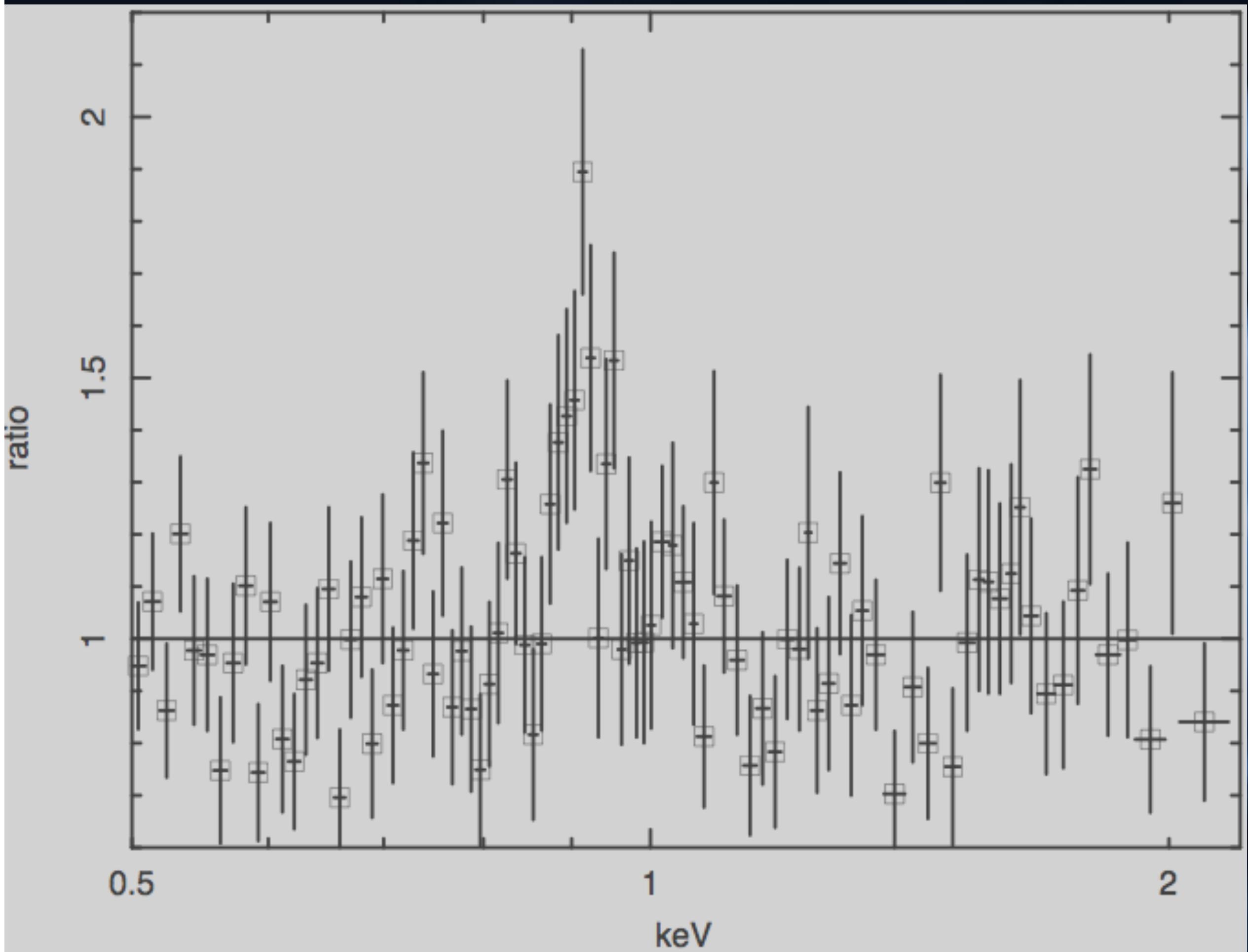
High-z star forming galaxies are pre-selected in color-color diagrams

z ~ 7 (z-mag drops)

Colors from COSMOS Type 2 AGN at z ~ 7

Need of deep imaging
In opt-nearIR (VISTA
PanSTARSS, LSST, …
And spectroscopy
JWST, ELT, Euclid, …

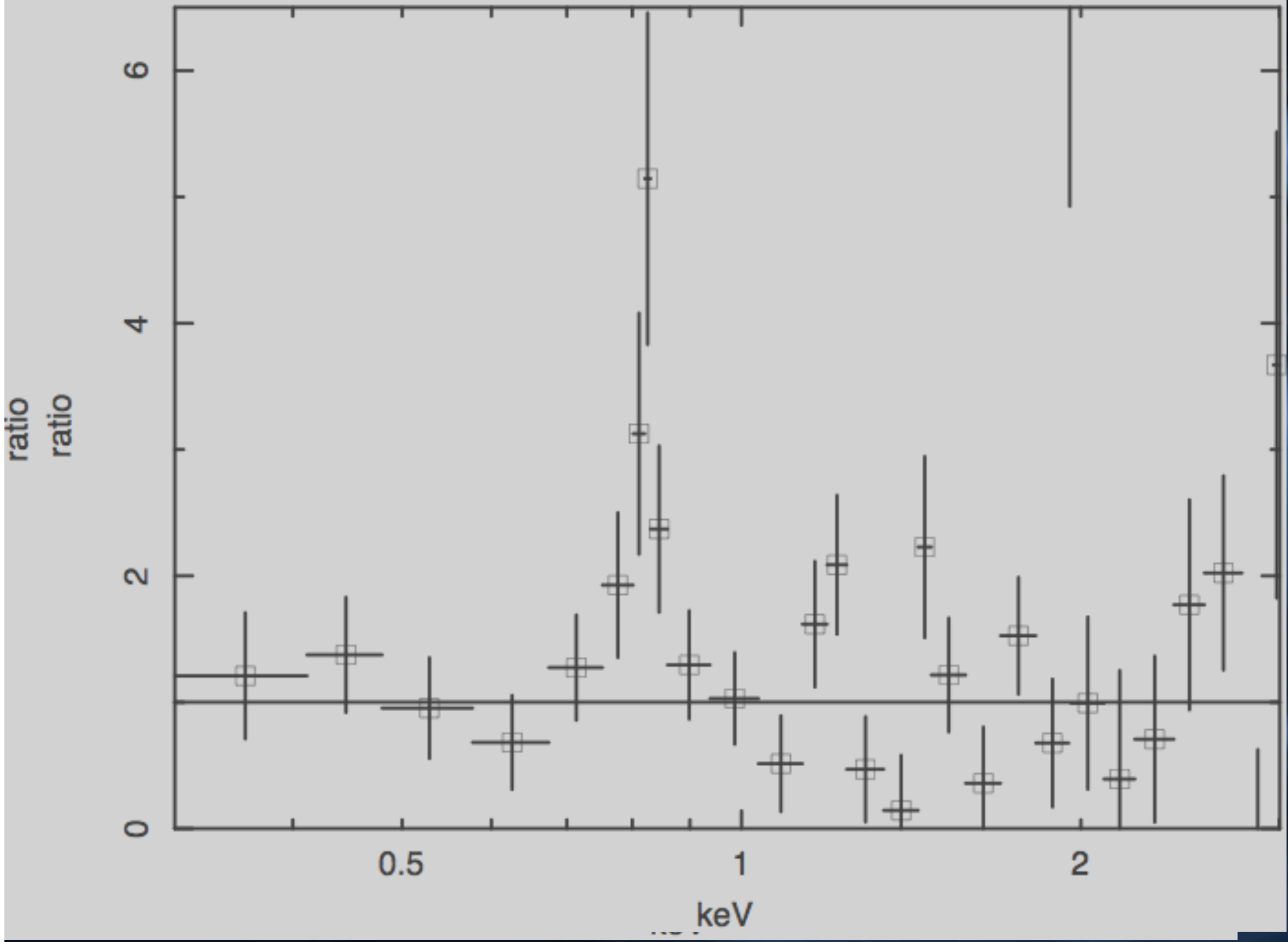
IXO X-ray Spectra



WFI simulation of a SDSS like QSO at z = 6, $L_X \sim 3 \times 10^{44}$ cgs - $F_X \sim 10^{-15}$ cgs line EW ~ 40 eV (obs-frame) .

100 ks (back. included)

IXO X-ray Spectra



WFI simulation of a SDSS like QSO at z = 6, $L_X \sim 3 \times 10^{44}$ cgs - $F_X \sim 10^{-15}$ cgs line EW ~ 40 eV (obs-frame) .

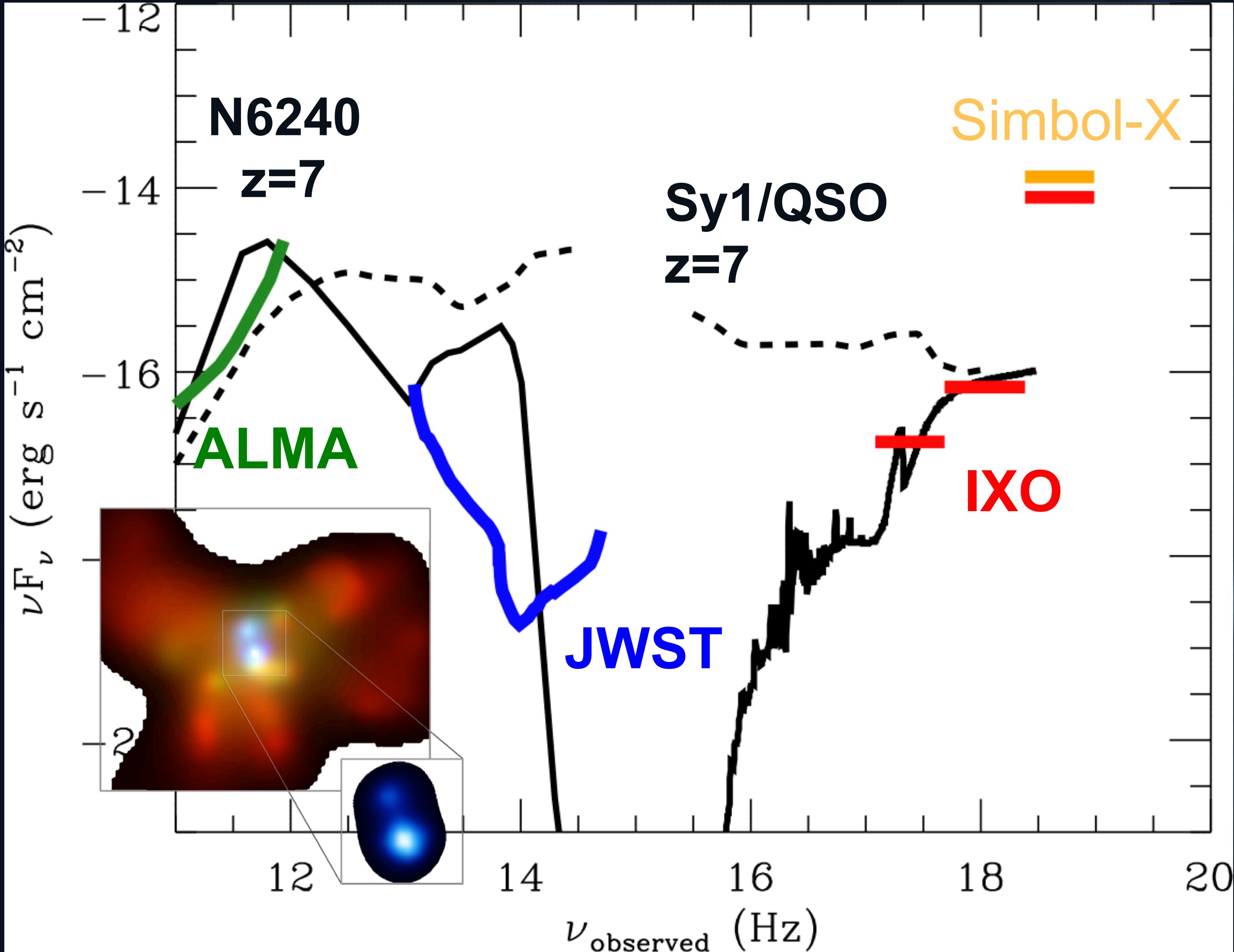
100 ks (back. included)

Obscured AGN at z = 7 ($L_X \sim 10^{43}$ cgs - $F_X \sim 10^{-16}$ cgs, line EW ~ 1.2 keV (rest-frame)

1 Ms (back included)

Redshift determination accuracy +- 0.2

Synergies



The high-z Universe is a key science driver of JWST & ALMA E-ELT - TMT

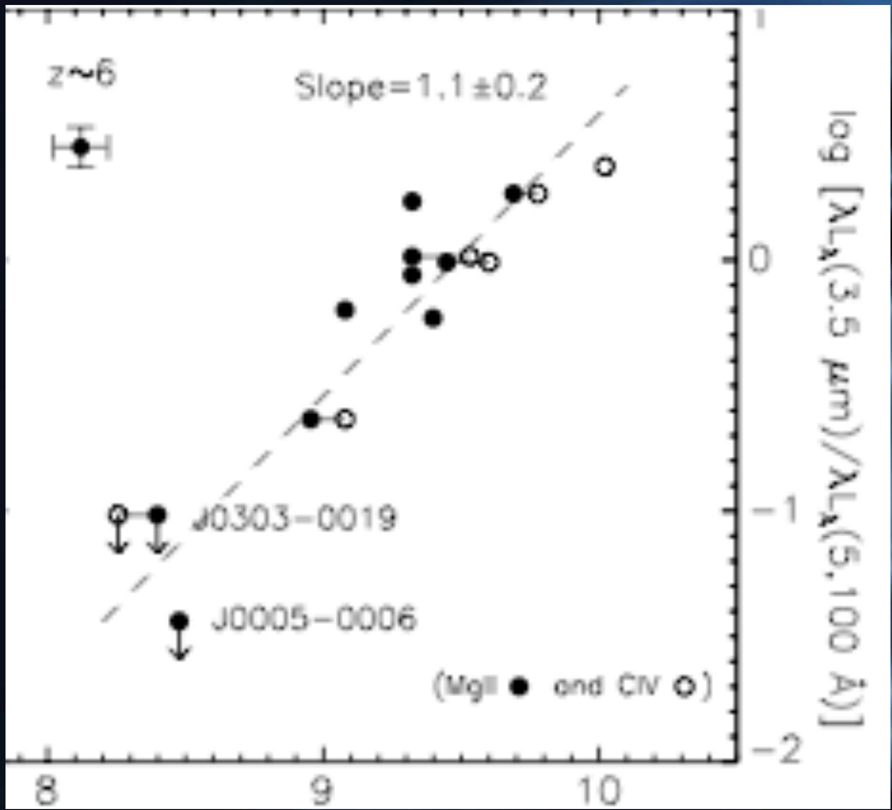
…

mainly SF

accretion & co-evolution --> IXO

Dust free QSO at z ~ 6

Hot Dust abundance



BH Mass

Jiang+10 Nature

Dust poor QSO
Have small BH masses
And high L/L_E (~ 2)

Early Stage of evolution

Gas and Metal content
From X-rays

Final remarks

- 5" HEW or better + ~350 arcmin^2 or larger + "clever" strategy + "enough" time invested in surveys
  --> build up a z > 6 XLF and constrain early BH growth
- IXO is well matched to the sensitivity of other future facilities to recognize high-z SMBH.
- IXO would provide excellent spectra for moderately bright high-z QSOs. Unique capability to identify through X-ray spectroscopy faint obscured AGN at high redshift.
- In the meantime Chandra + XMM Legacy programs AND aggressive multiband data analysis strategies exploiting synergies with HST, HERSCHEL, ALMA, … (SDSS-like XLF)
- Deep and Large optical and near-IR surveys (PanSTARRS, VISTA, LSST, …) and deep spectroscopy (JWST, Euclid, …) are crucial for a joint selection of high-z samples